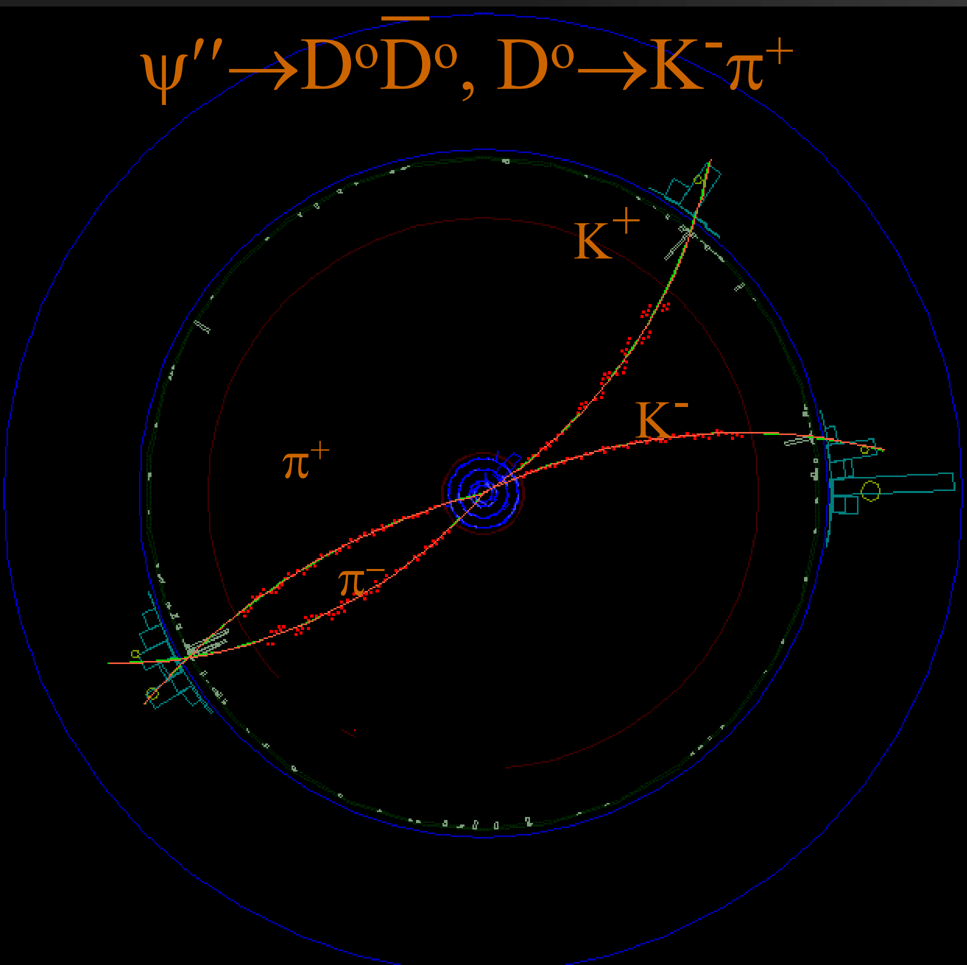
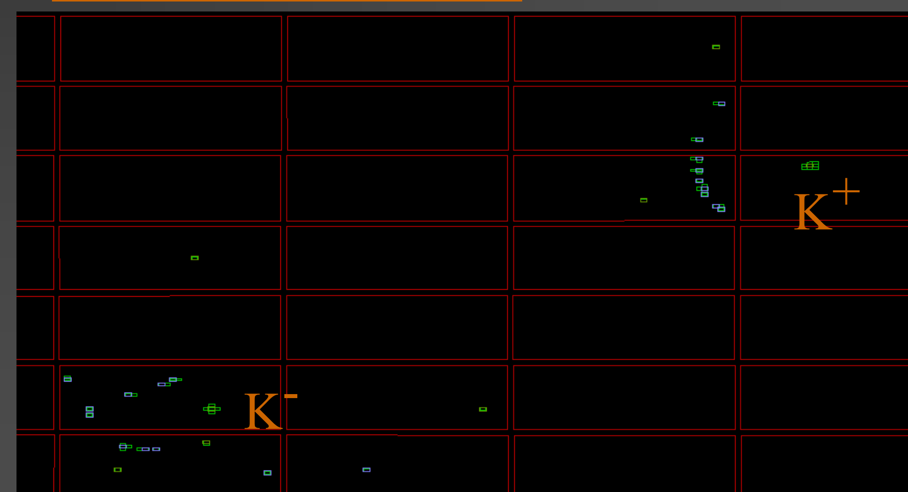
Charm Physics from CLEOc



Sheldon Stone,
Syracuse University

"I charm you, by my once-commended beauty"
Julius Cæsar, Act II, Scene I



Why Study Charm? – Overview

- Tests of Theoretical Models necessary to interpret critical CKM data, usually obtained from B decays
- CKM Matrix elements: Charm decays can be used to determine directly V_{cd} & V_{cs}, indirectly V_{ub} and contribute to V_{cb}
- Engineering measurements: e. g. absolute $\mathcal{B}$'s (& some inclusive ones, i.e. $D^{o,+} \to \phi X$)
- New Physics: May see in charm directly
  - SM CPV suppressed, perhaps also rare decays & mixing

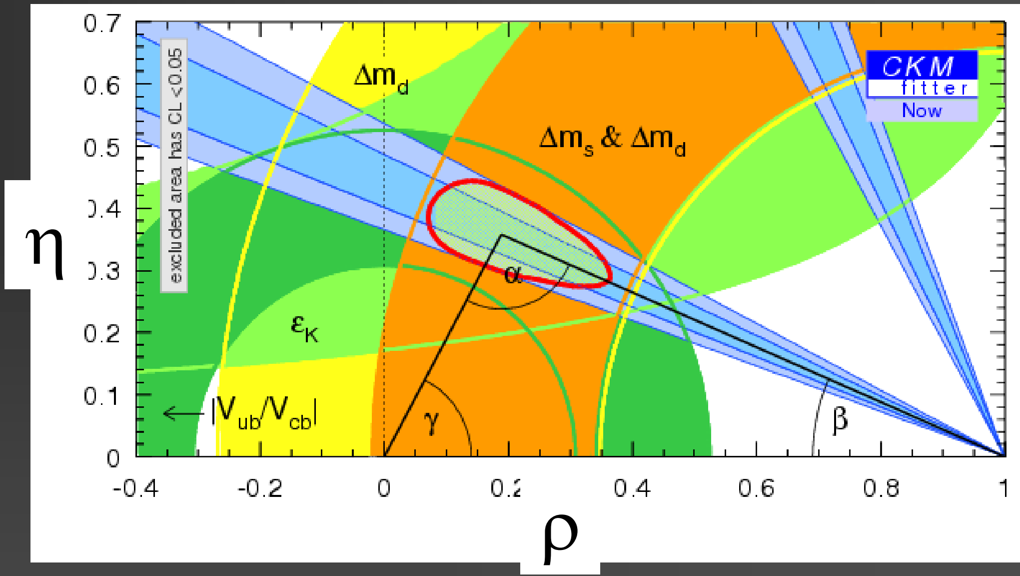
Use of Charm data to improve B measurements, etc..

Some examples:

Item: B_s mixing

- To relate constraints on CKM matrix in terms of say ρ & η need to use theoretical estimates of $f_{B_s}{}^2 B_{B_s} / f_{B_d}{}^2 B_{B_d}$
- CLEO-c's job: Measure f_{D_s}/f_{D^+} to check theoretical lattice calculations, best unquenched lattice.

Artists view of current constraints ±1σ bands, not precise

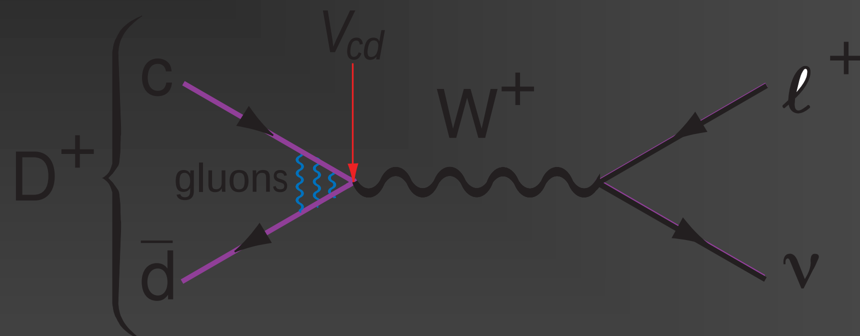


- Idea is that (η,ρ) can be determined in several ways, differences will indicate new physics

Leptonic Decays: D $\to \ell^+ \nu$

Introduction: Pseudoscalar decay constants: c and $\bar{q}$ can annihilate, probability is $\propto$ to wave function overlap

Example :



In general for all pseudoscalars:

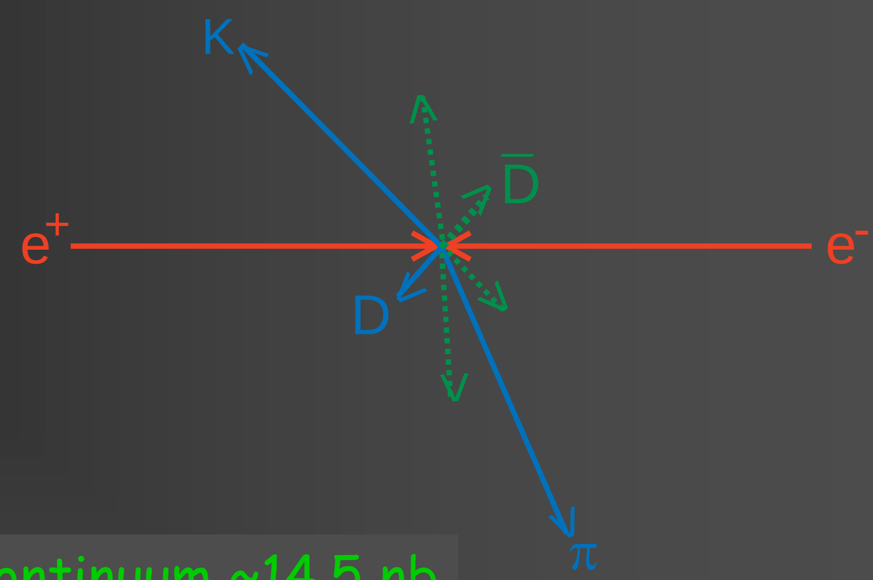
$$\Gamma(P^+ \to \ell^+ \nu) = \frac{1}{8\pi} G_F^2 f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2 |V_{Qq}|^2$$

Calculate, or measure if V_{Qq} is known

Experimental methods

- $D\bar{D}$ production at threshold: used by Mark III, and more recently by CLEO-c and BES-II.
  - Unique event properties
    - Only $D\bar{D}$ not $D\bar{D}x$ produced
  - Large cross sections:

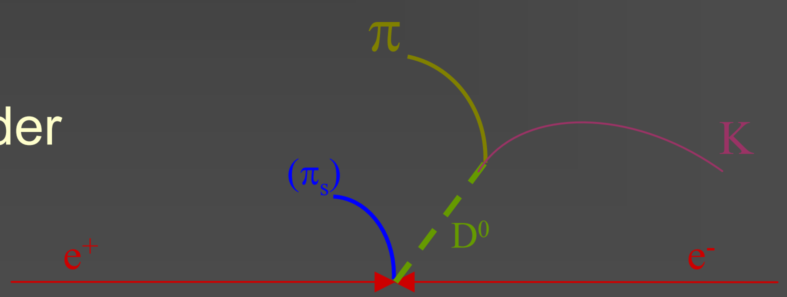
$\sigma(D^o\bar{D}^o) =$ 3.72±0.09 nb
$\sigma(D^+D^-) =$ 2.82±0.09 nb
World Ave



Continuum ~14.5 nb

  - Ease of B measurements using "double tags“
  - $\mathcal{B}_A$ = # of A/# of D's

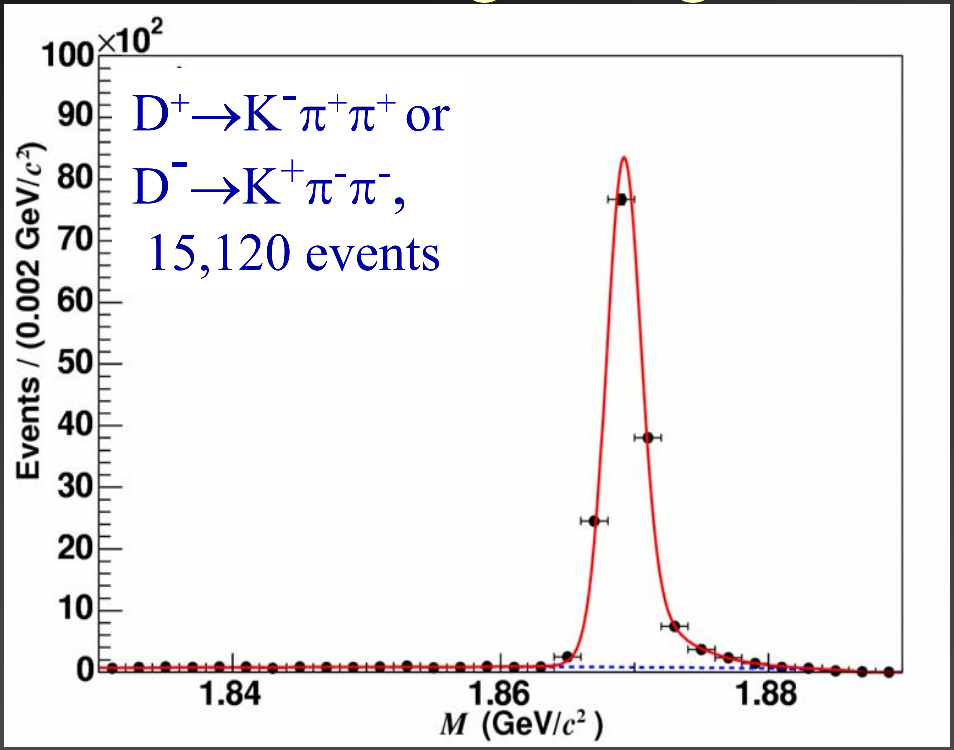
- B-factories (e^+e^-) + fixed target & collider experiments at hadron machines
  - D displaced vertex
  - $D^{*+} \rightarrow \pi^+ D^0$ tag

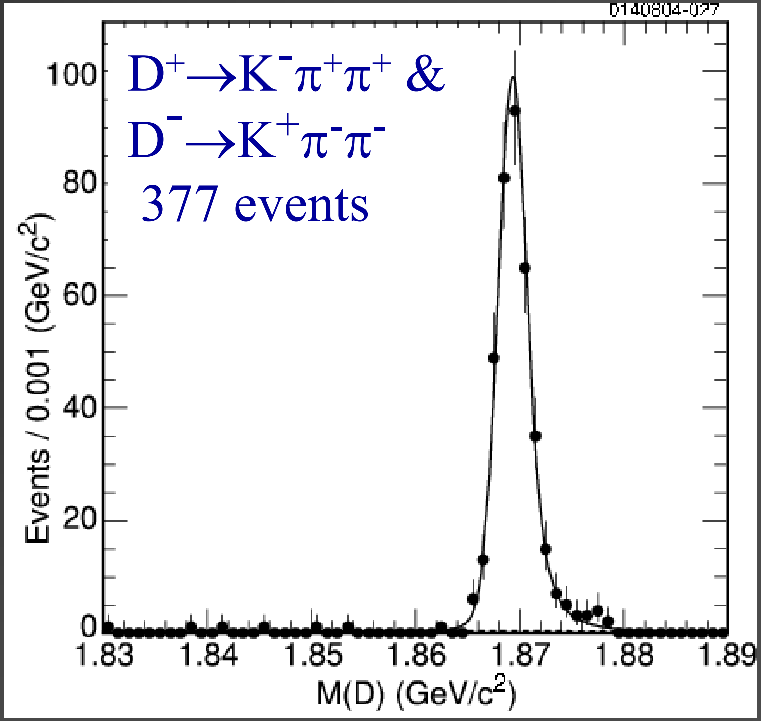


$D^+ \to K^- \pi^+ \pi^+$ at the ψ'' (CLEO-c)

Single tags

Double





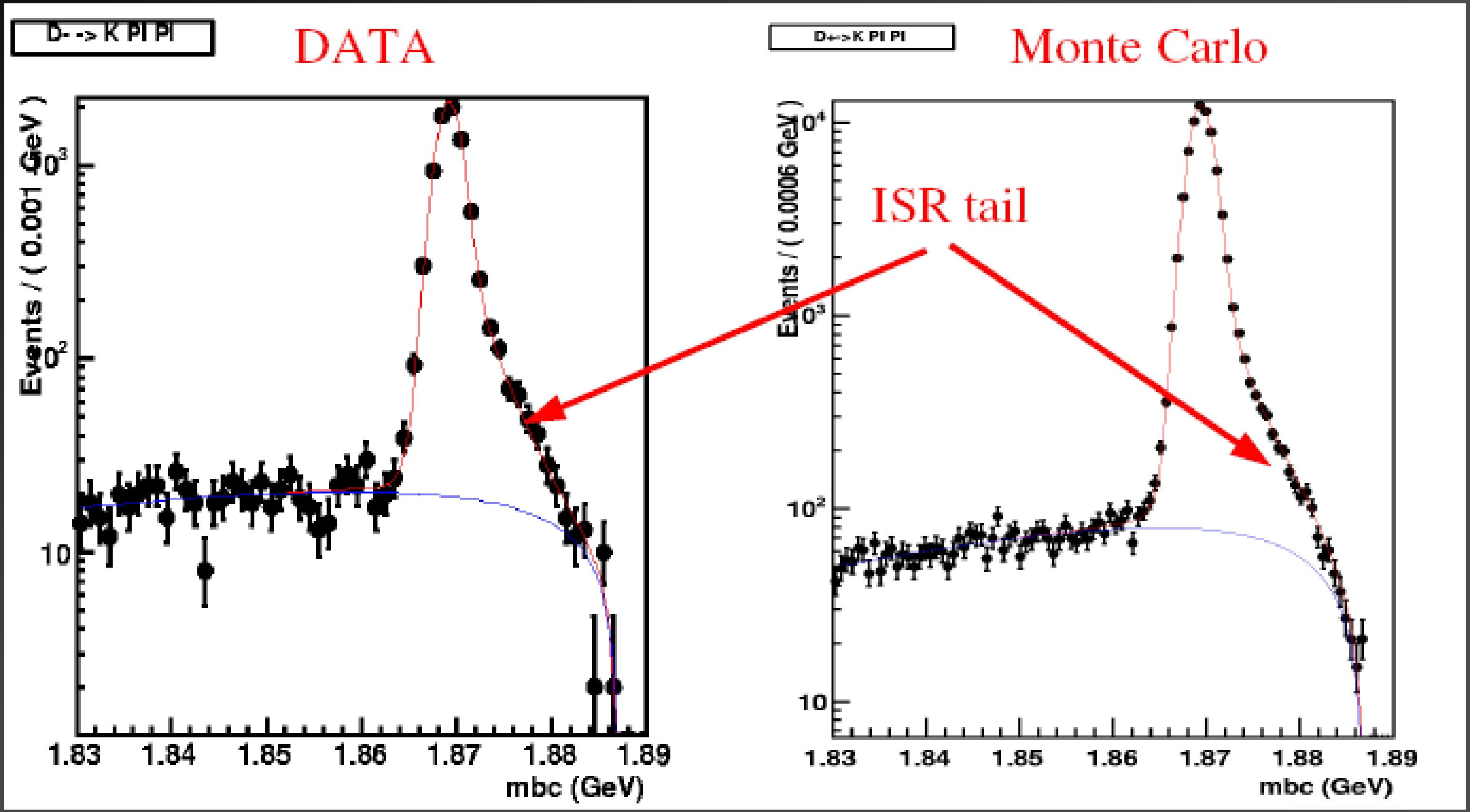
$$M_D^2 = \sum E_i^2 - \sum \vec{P}_i^2 = E_{beam}^2 - \sum \vec{P}_i^2$$

57 pb^{-1} of data at $\psi(3770)$, CLEO now has 281 pb^{-1}

Absolute *B* Methodology

- Idea: ratio of double to single tags determines *B*
  - $N_i = 2\varepsilon_i \mathcal{B}_i N_{D\bar{D}}$, $N_{ii} = 2\varepsilon_{ii} \mathcal{B}_i^2 N_{D\bar{D}}$
  - $\therefore N_{ii}/N_i = (B_i/2)(\varepsilon_{ii}/\varepsilon_i)$, with $\varepsilon_{ii}/\varepsilon_i \approx 1$
- Modes
  - D^o: $K^-\pi^+$, $K^-\pi^+\pi^o$, $K^-\pi^+\pi^+\pi^-$,
  - D^+: $K^-\pi^+\pi^+$, $K_S\pi^+$, $K^-\pi^+\pi^+\pi^o$, $K_S\pi^+\pi^+\pi^-$, $K_S\pi^+\pi^o$, $K^-K^+\pi^+$
- Determine the single tag yields in each mode
- Determine the double tag yields in all combined modes

Yields Determined Precisely



- Include Initial State Radiation in fitting function
- Double tag yields are easier, due to extremely small backgrounds

Absolute $\mathcal{B}$ Results

$\mathcal{B}(D^+ \to K^- \pi^+ \pi^+)$

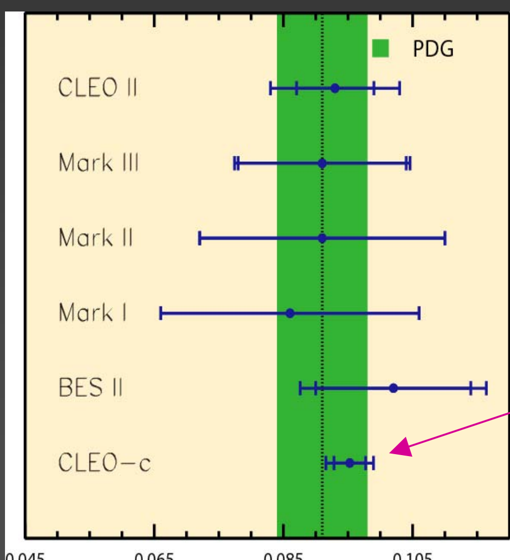
Three best measurements

$\mathcal{B}$ (%)	Error(%)	Source
9.3±0.6±0.8	10.8	CLEO II
9.1±1.3±0.4	14.9	MK III
9.52 ±0.25±0.27	3.9	CLEO-c

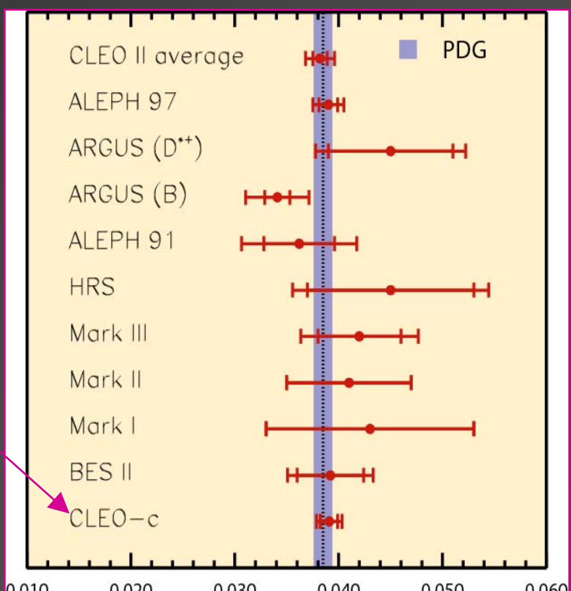
$\mathcal{B}(D^o \to K^- \pi^+)$

Three best measurements

$\mathcal{B}$ (%)	Error(%)	Source
3.82±0.07±0.12	3.6	CLEO II
3.90±0.09±0.12	3.8	ALEPH
3.91±0.08 ±0.09	3.1	CLEO-c



CLEO-c
(not in average)



Leptonics & Semileptonics at CLEO-c

- Ease of leptonic & semileptonic decays using double tags & MM^2 technique

$$MM^2 = (E_D - E_\ell - E_{hadrons})^2 - (\vec{p}_D - \vec{p}_\ell - \vec{p}_{hadrons})^2$$

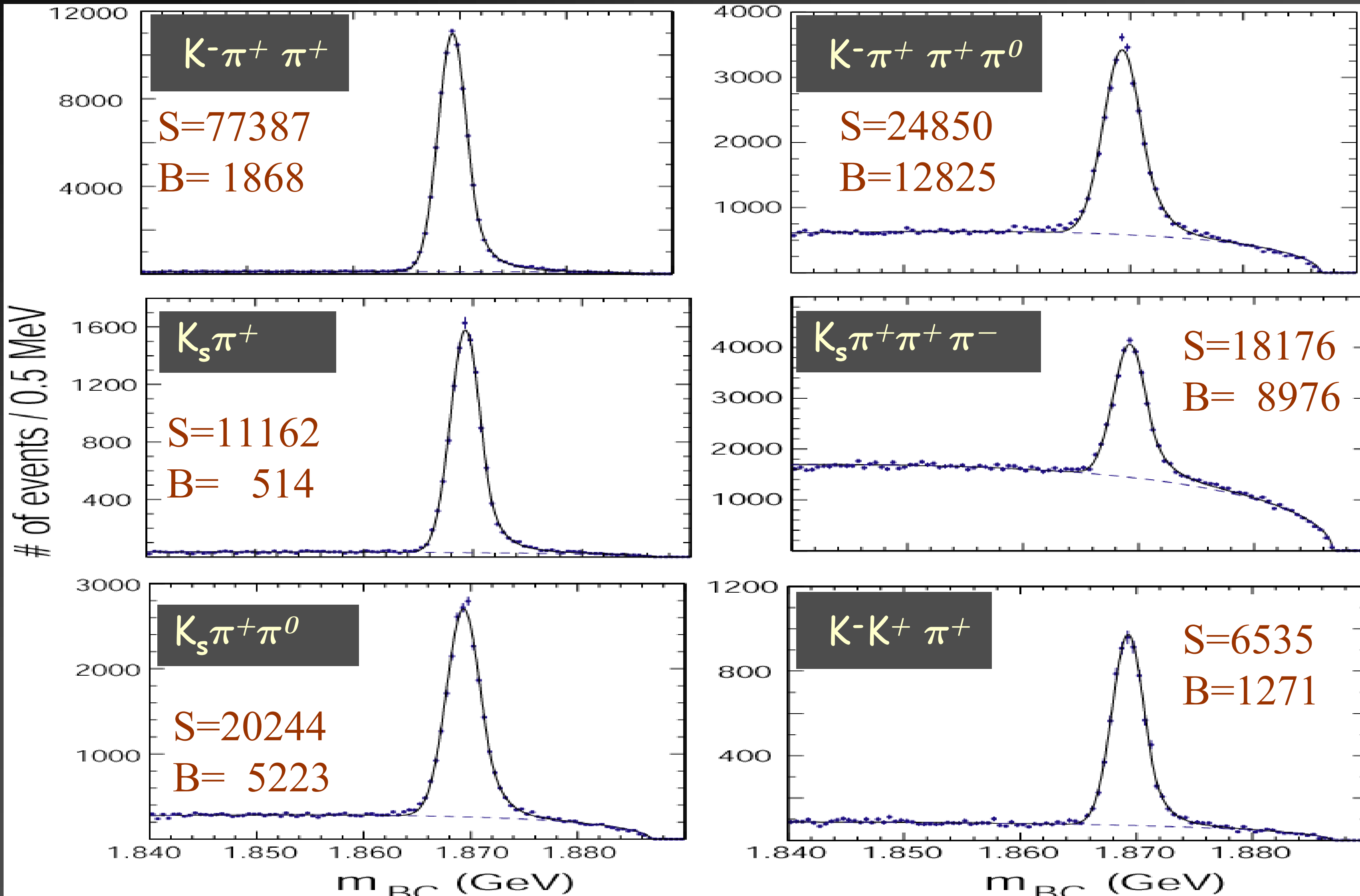
We know $E_D = E_{beam}$, $\vec{p}_D = -\vec{p}_{\bar{D}}$

- Search for peak near MM^2=0
- Since resolution ~ $M^2_{\pi^o}$, reject extra particles with calorimeter & tracking
- Note that this method can be used to evaluate systematic errors on ε, simply by using double tags with one missing track
- Sometimes people use $U_{miss} = E_{miss} - |\vec{P}_{miss}|$

Technique for $D^+ \rightarrow \mu^+\nu$

- Fully reconstruct one D^-
- Seek events with only one additional charged track, *in detector barrel* $|\cos\theta|<0.81$, & no additional photons > 250 MeV to veto $D^+ \rightarrow \pi^+\pi^o$
- Charged track must deposit only minimum ionization in calorimeter
- Constraint D^- decay products to have exact D mass; equivalent to full kinematic fit
- Compute MM^2: If close to zero then almost certainly we have a $\mu^+\nu$ decay

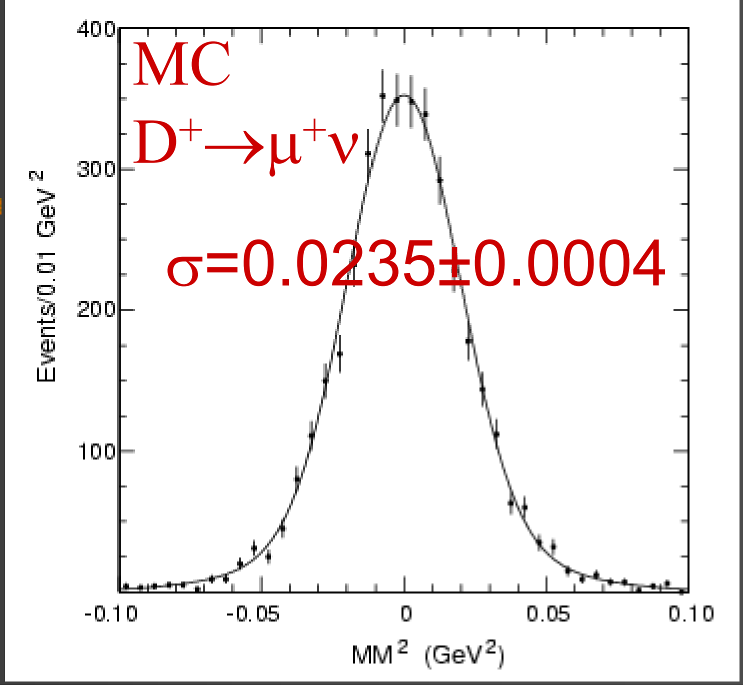
Single Tag Sample

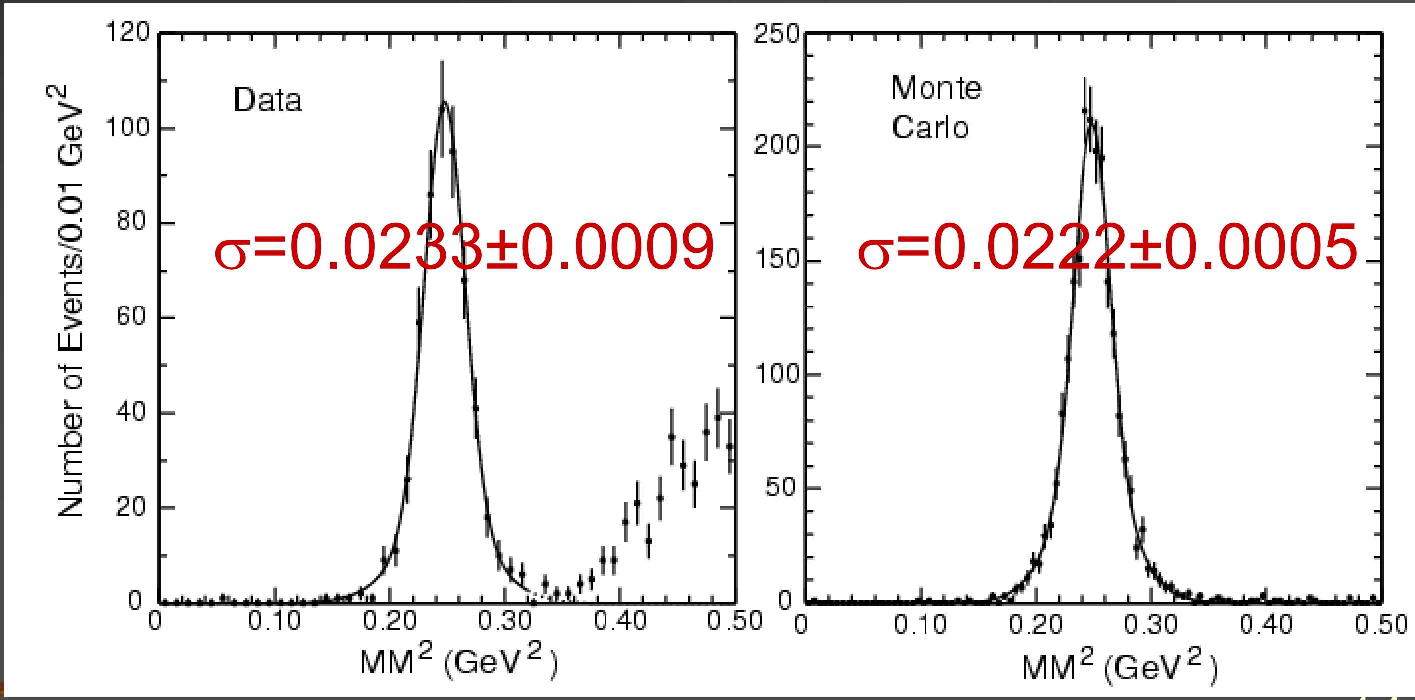


- From 281 pb^{-1}, 158,354 tags

MM^2 Resolution

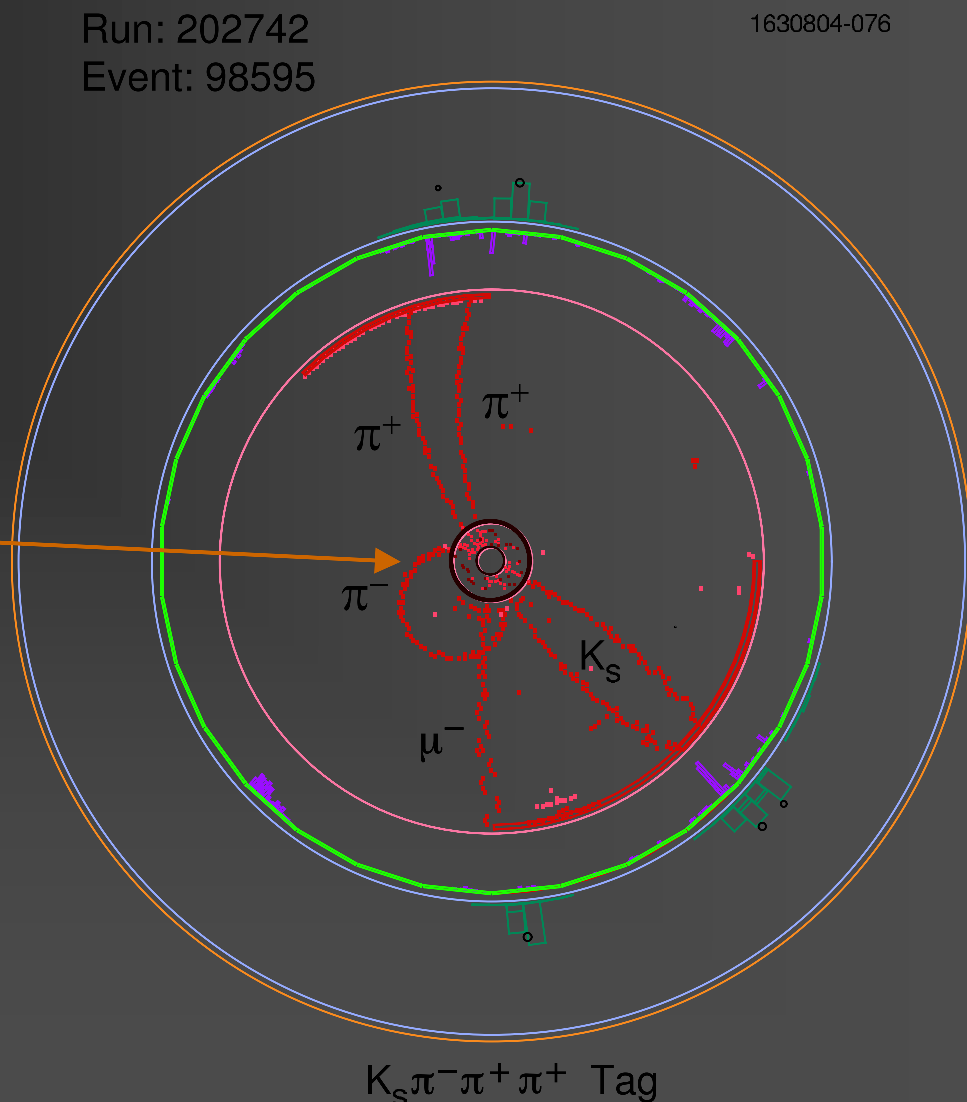
- MC gives σ=0.0235±0.0004 GeV^2
- Check with data use $D^o \to K_S\pi^+$ & ignore K_S





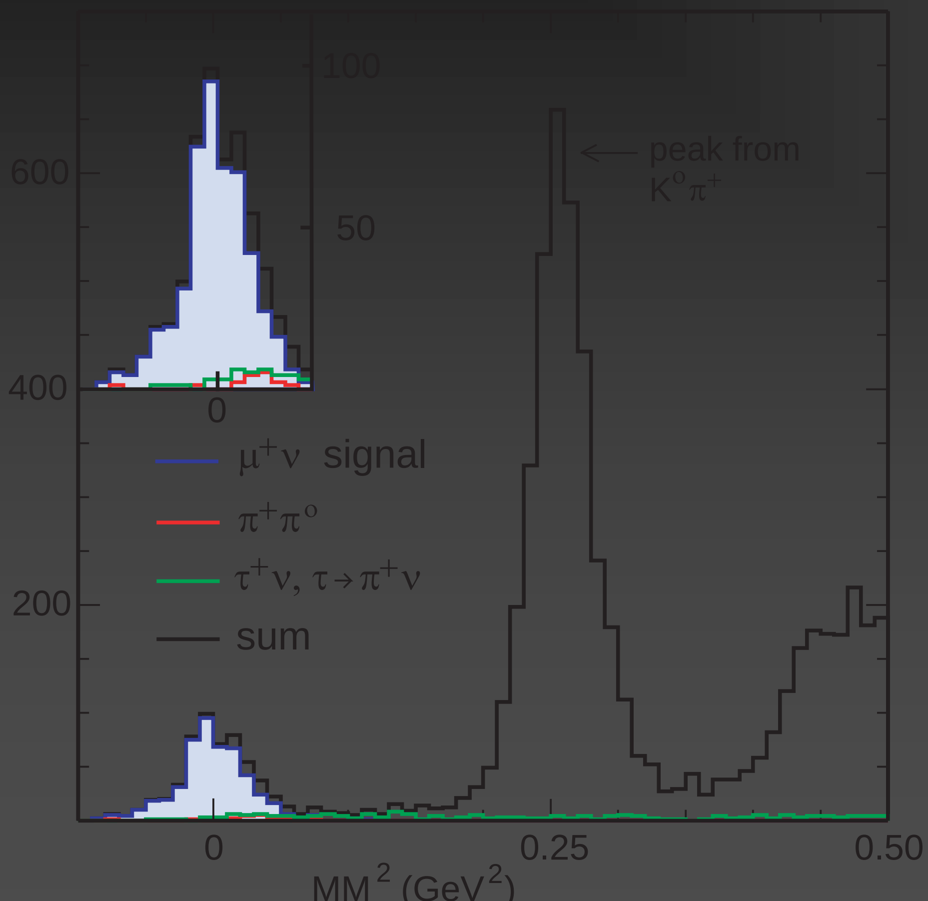
A "Typical" Event

- Nothing left in event besides D_S^- tag and μ^+
- Note the 50 MeV curler

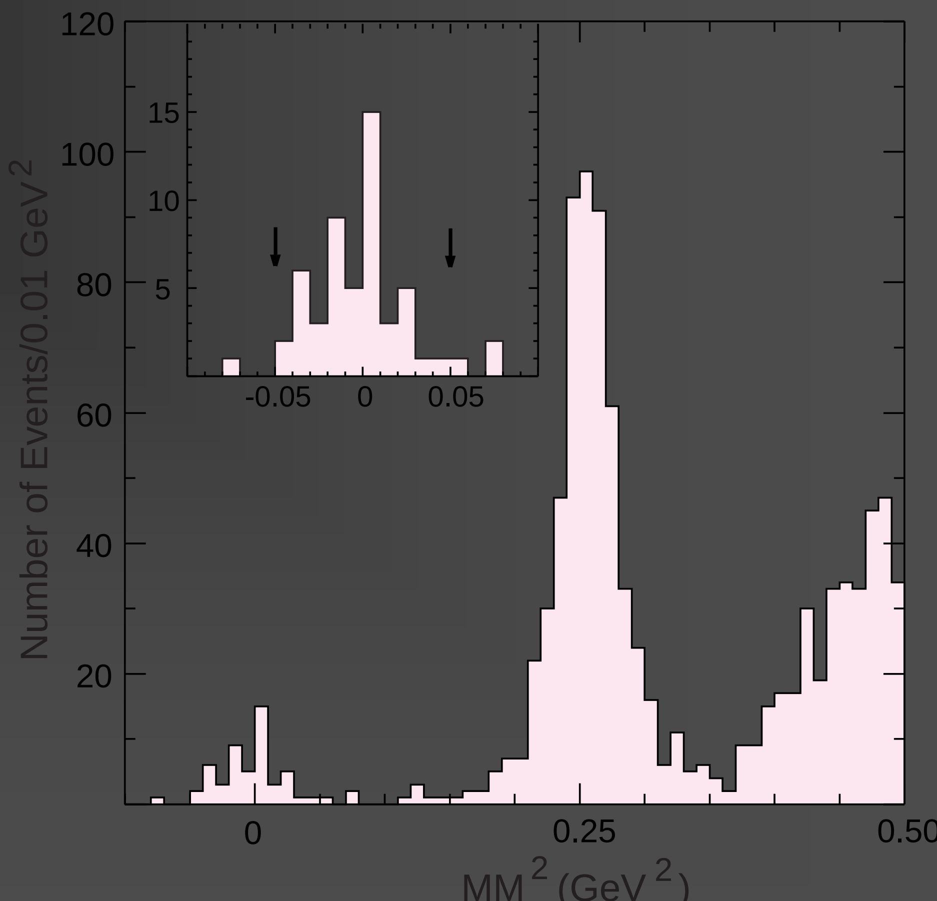


Measurement of f_{D^+}

MC Expectations from 1.7 fb^{-1}, 6X this sample

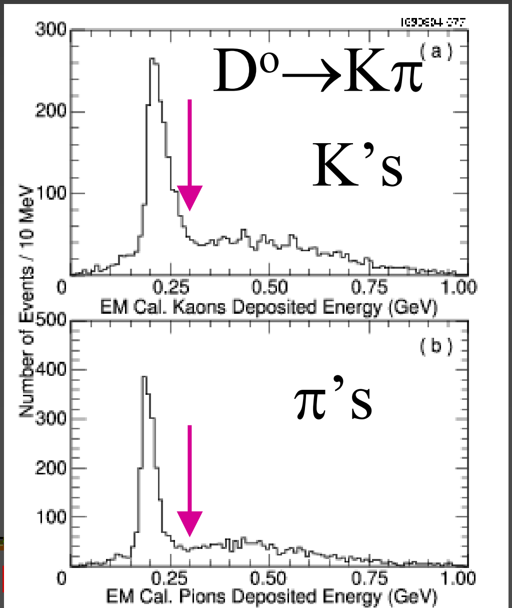


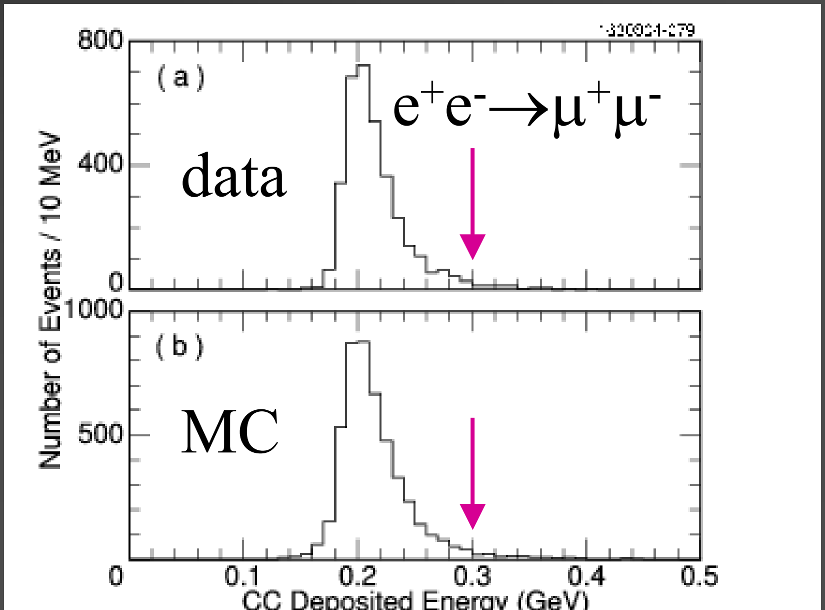
Data have 50 signal events in 281 pb^{-1}



Backgrounds

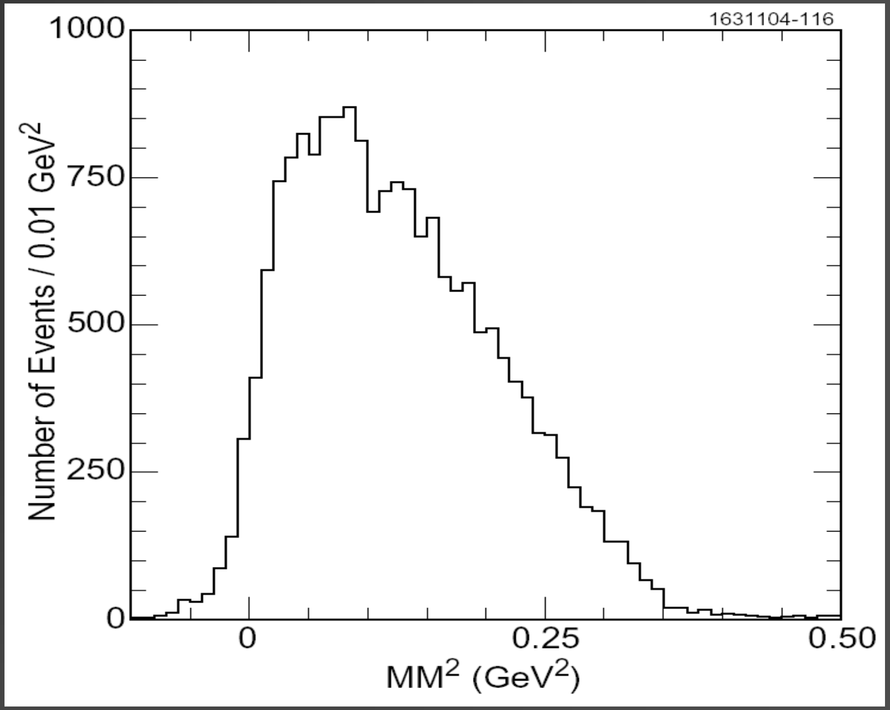
- $D^+ \to \pi^+\pi^o$, MM^2 peaks at 0.018 GeV^2 within 0.025 GeV^2 resolution (1 σ), *B* measured by CLEO
- Defeated by
  - γ veto of 250 MeV, very effective for a ~0.9 GeV π^o
  - Minimum ionization in EM cal < 300 MeV of deposited energy kills 40% of pions & is 98% efficient





$D^+ \to \tau^+\nu$, $\tau^+ \to \pi^+\nu$ Background

- Calorimeter requirement eliminates 40% of the pions
- Since $\mathcal{B}(D^+ \to \tau^+\nu) = 2.65 \cdot \mathcal{B}(D^+ \to \mu^+\nu)$ easy to evaluate
- Some hope of measuring this process with more data, which would provide a test of Lepton Universality



Other Backgrounds

- Tail of the $K^o\pi^+$
  - Evaluated using MC, yields 0.44±0.22 events
  - Evaluated using Double tags, one tag consistent having two tracks, one a K & the other a π by RICH id. Then we ignore the K. This gives 0.33±0.19±0.02 events
- Other D^o, D^+, Continuum & radiative return ($\gamma\psi'$) events show no background using large MC samples

Deriving a Value for f_{D^+}

Backgrounds		
Mode	$\mathcal{B}$(%)	# Events
$\pi^+\pi^0$	0.13±0.02	1.40±0.18±0.22
$K^0\pi^+$	2.77±0.18	0.33±0.19±0.02
$\tau^+\nu$ ($\tau \rightarrow \pi^+\nu$)	2.65*$\mathcal{B}(D^+ \rightarrow \mu^+\nu)$	1.08 ±0.15±0.02
Other D^+, D^o	0	<0.4, <0.4 @ 90% cl
+ Continuum	0	<1.2 @ 90% c.l.
Total		$2.81 \pm 0.30^{+0.84}_{-0.27}$

- Tags are 158,354 events
- $\mathcal{B}(D^+ \rightarrow \mu^+\nu) = (4.40 \pm 0.66^{+0.09}_{-0.12}) \times 10^{-4}$
- $f_{D^+} = (222.6 \pm 16.7^{+2.3}_{-3.4})$ MeV
- $\mathcal{B}(D^+ \rightarrow e^+\nu) < 2.4 \times 10^{-5}$ @ 90% c.l.

Efficiencies: μ^+ detection (69.4%); extra shower (96.1%); correction for easier tag reconstruction in $\mu^+\nu$ events (1.5%)

Systematic Errors

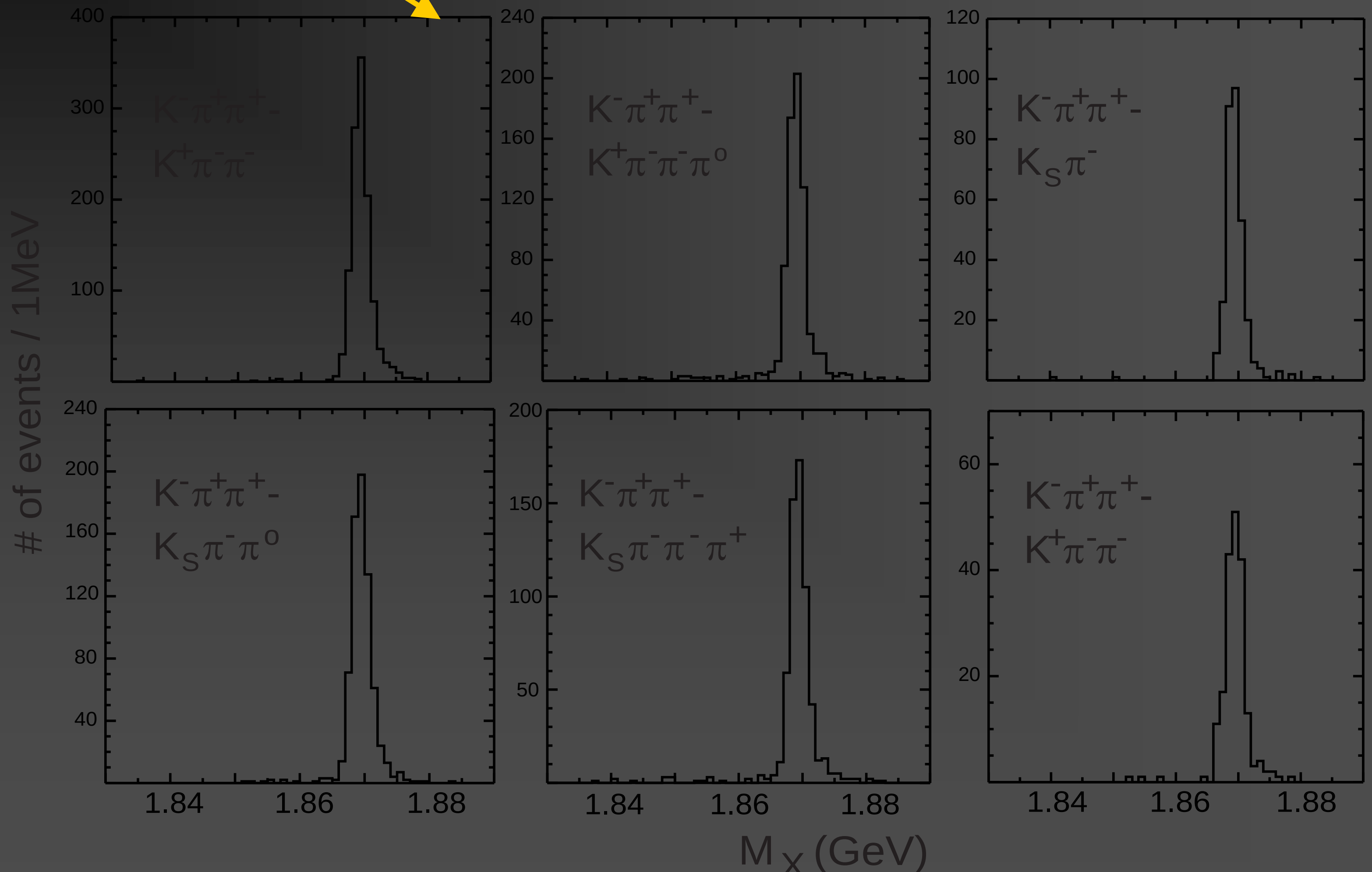
Source of Error	%
Finding the μ^+ track	0.7
Minimum ionization of μ^+ in EM cal	1.0
Particle identification of μ^+	1.0
MM^2 width	1.0
Extra showers in event > 250 MeV	0.5
Number of single tag D^+	0.6
Monte Carlo statistics	0.4
Background	+ 0.6, -1.7
Total	**+2.1, -2.5**

Evaluation of Systematic Errors

- Systematic errors are small because data is used to evaluate most of the cut efficiencies
- Example: Extra showers in event > 250 MeV. Use Double tag event sample, then measure the product ε of two tags
  - Use $K^-\pi^+\pi^+$ as one tag, due to large clean sample
  - Use p and E conservation to do a full kinematic fit to both D^- & D^+ decays in each event
  - Let the D mass float in the fit, M_X

Kinematic Fits to Define Double Tags

- Prior to χ^2 cut, there is a small bkgrd
- Most bkgrd gone post cut



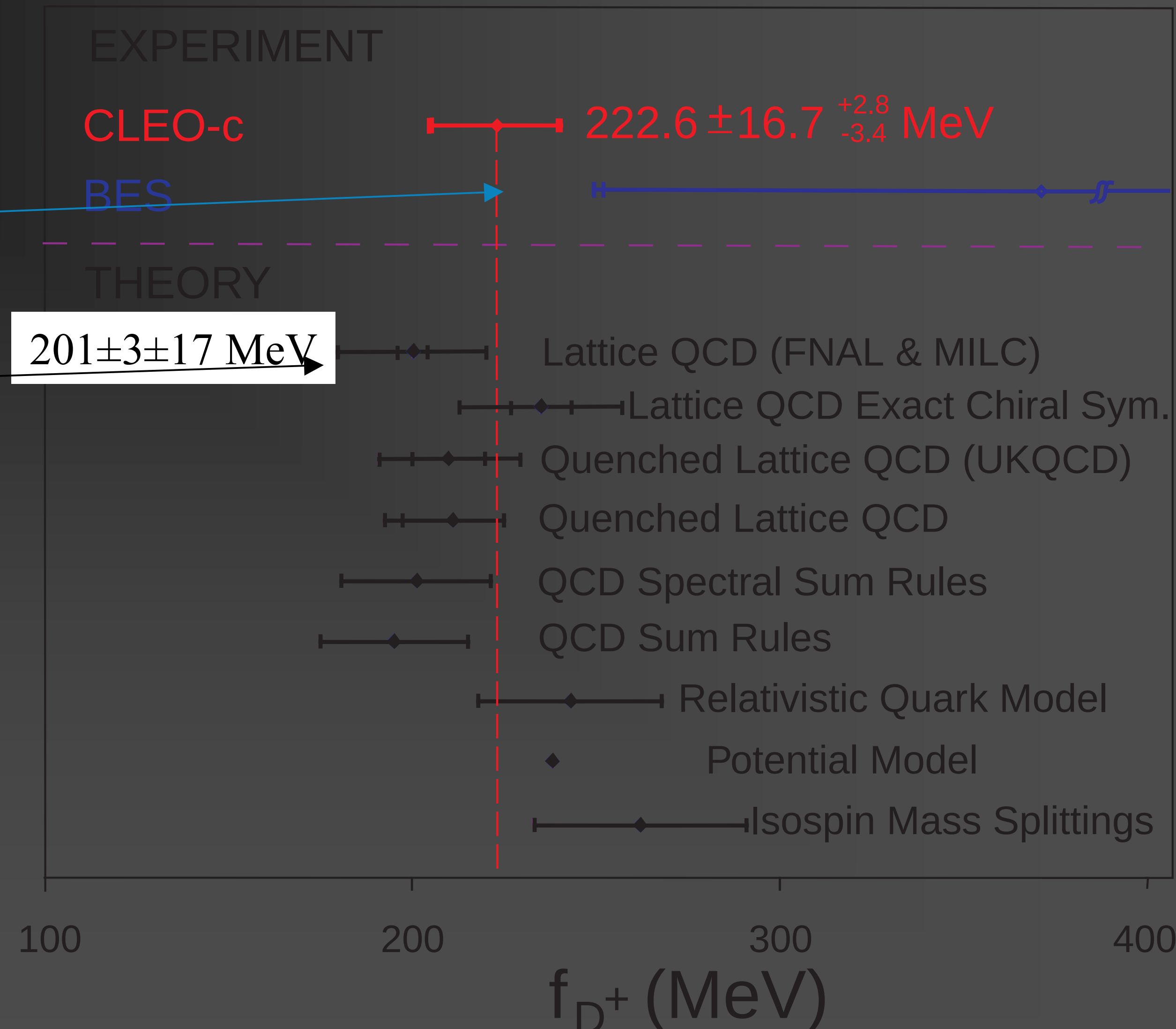
Efficiency of 250 MeV Extra γ Cut

Mode 1	Mode 2	# of events	$\#(E_{\gamma>250\ \mathrm{MeV}})$	$\epsilon(\%)$ of Mode 1
$K^+\pi^-\pi^-$	$K^-\pi^+\pi^+$	861	82	95.2 ± 0.5
$K^+\pi^-\pi^-\pi^o$	$K^-\pi^+\pi^+$	468	25	99.4 ± 1.2
$K_S\pi^-$	$K^-\pi^+\pi^+$	242	24	94.8 ± 2.0
$K_S\pi^-\pi^-\pi^+$	$K^-\pi^+\pi^+$	406	28	97.9 ± 1.4
$K_S\pi^-\pi^o$	$K^-\pi^+\pi^+$	524	42	96.7 ± 1.3
$K^+K^-\pi^-$	$K^-\pi^+\pi^+$	143	17	92.9 ± 2.8
Weighted Average				96.3 ± 0.4

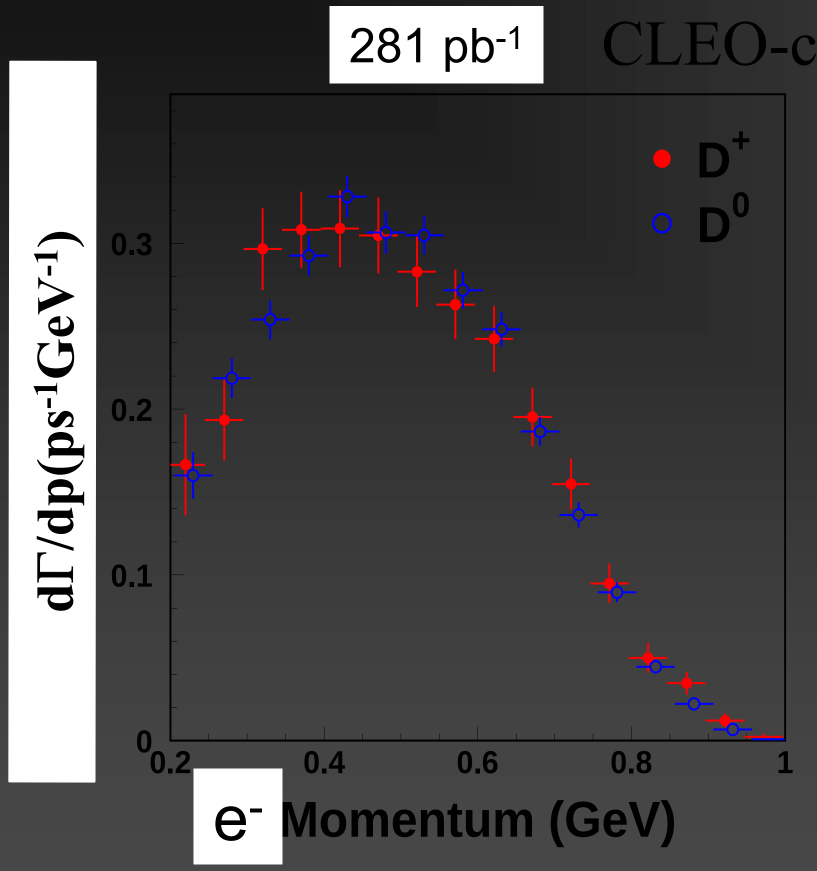
- Error of 0.4% is statistical
- Systematic error arises from difference in this situation and a single tag, estimated by MC as 0.5% (i.e. difference between $K\pi\pi$-$K\pi\pi$ & $K\pi\pi-\mu\nu$)
- Overall, systematic errors are small now, can be lowered, and will not present a limit to improved measurement

Comparison to Theory

- BES measurement based on 2.67±1.74 events
- Current Lattice measurement (unquenched light flavors) is consistent
- But systematic errors on theory & statistical errors on data are still large



Inclusive Semileptonic Branching Fractions



preliminary

Lab momentum spectrum – no FSR correction

- Tagged sample: only "golden modes" $D^0 \to K^-\pi^+$ & $D^+ \to K^-\pi^+\pi^+$
- Identify e, π, K right-sign and wrong-sign samples, use unfolding matrix$\to$true e population.
- Correction for p_{e^-} cut

$$B(D^+ \to Xe\nu) = (16.19 \pm 0.20 \pm 0.36)\%$$

$$\sum B(D^+ \to Xe\nu)_{excl} = (15.1 \pm 0.50 \pm 0.5)\%$$

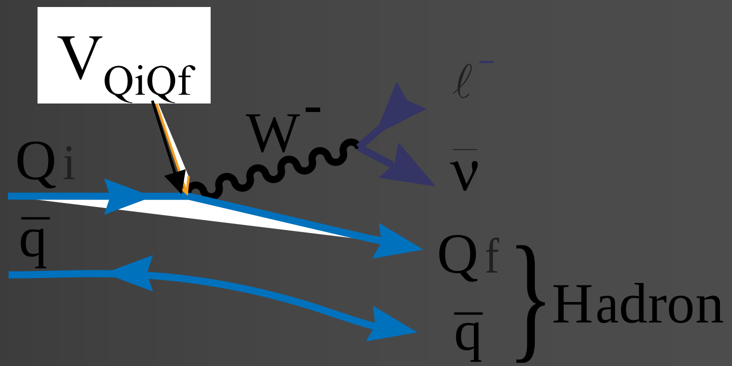
$$B(D^0 \to Xe\nu) = (6.45 \pm 0.17 \pm 0.15)\%$$

$$\sum B(D^0 \to Xe\nu)_{excl} = (6.1 \pm 0.2 \pm 0.2)\%$$

$$\frac{\Gamma(D^+ \to Xe^+\nu)}{\Gamma(D^o \to Xe^+\nu)} = 1.01 \pm 0.03 \pm 0.03$$

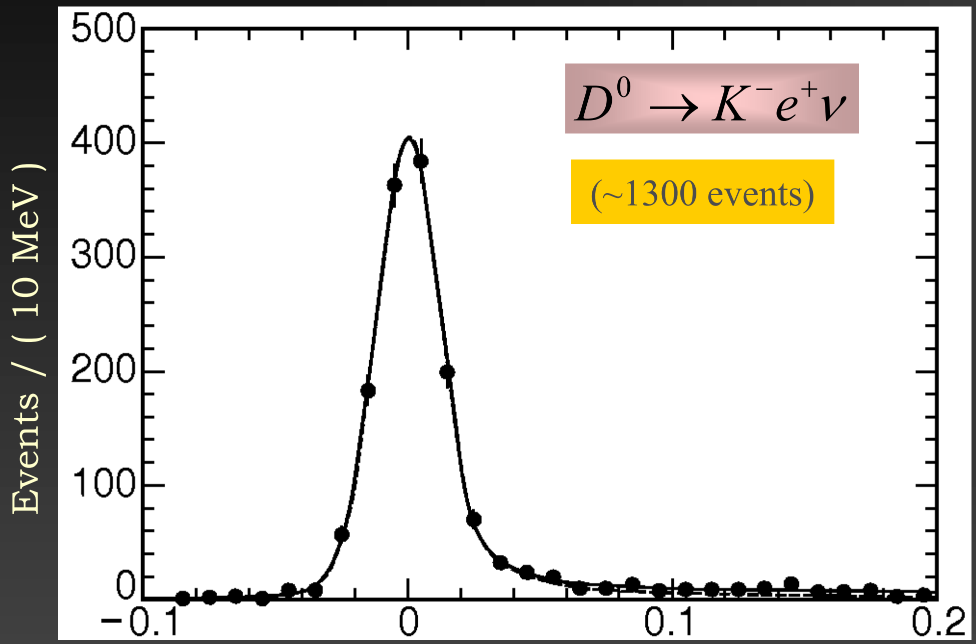
Exclusive Semileptonic Decays

- Best way to determine magnitudes of CKM elements, in principle, is to use semileptonic decays. Decay rate $\alpha|V_{QiQf}|^2$
- This is how V_{us} (λ) and V_{cb} (A) have been determined



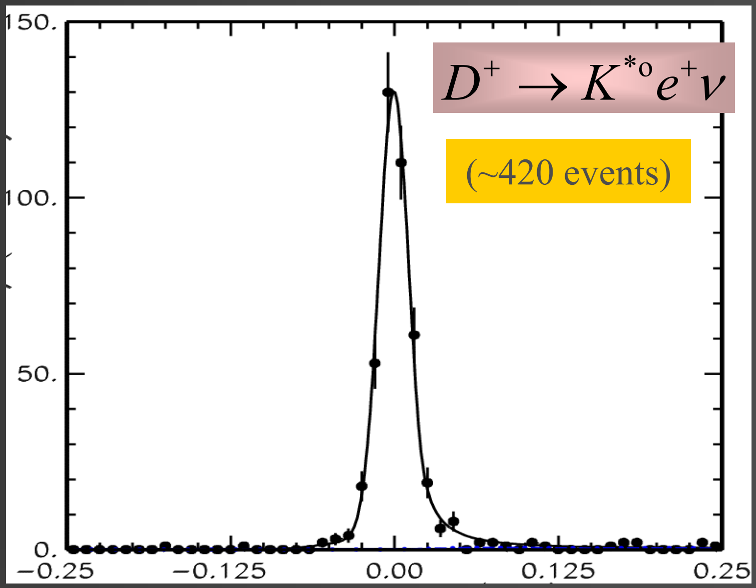
- Kinematics for hadron P: $q^2 = \left(p_D^\mu - p_P^\mu\right)^2 = m_D^2 + m_P^2 - 2E_P m_D$
- Matrix element in terms of form-factors (for D→Pseudoscalar $\ell^+ \nu$
- $\left\langle P(P_P)\middle|J_\mu\middle|D(P_D)\right\rangle = f_+(q^2)(P_D+P_P)_\mu + f_-(q^2)(P_D-P_P)_\mu$
- For ℓ = e, contribution of $f_-(q^2) \to 0$

Cabibbo Favored Semileptonic Decays



U = E$_{miss}$– |P$_{miss}$| (GeV)

$\mathcal{B} = (3.44 \pm 0.10 \pm 0.10)\%$

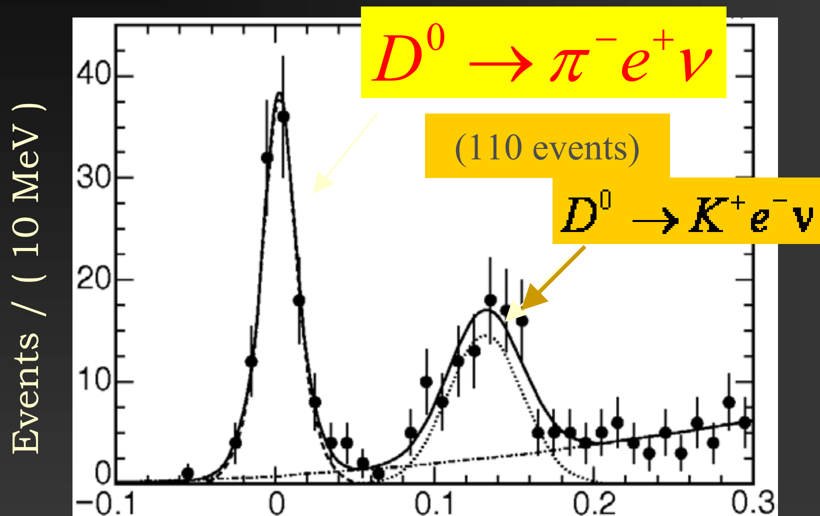


U = E$_{miss}$– |P$_{miss}$| (GeV)

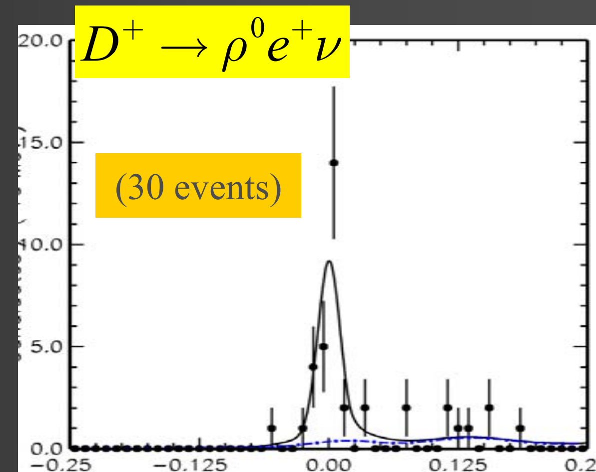
$\mathcal{B} = (5.70 \pm 0.28 \pm 0.25)\%$

These are the dominant modes, so backgrounds are very small

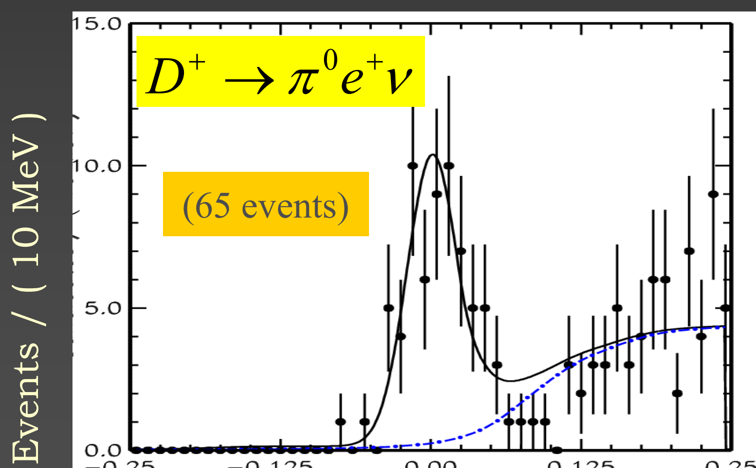
Cabibbo Suppressed Semileptonic Decays



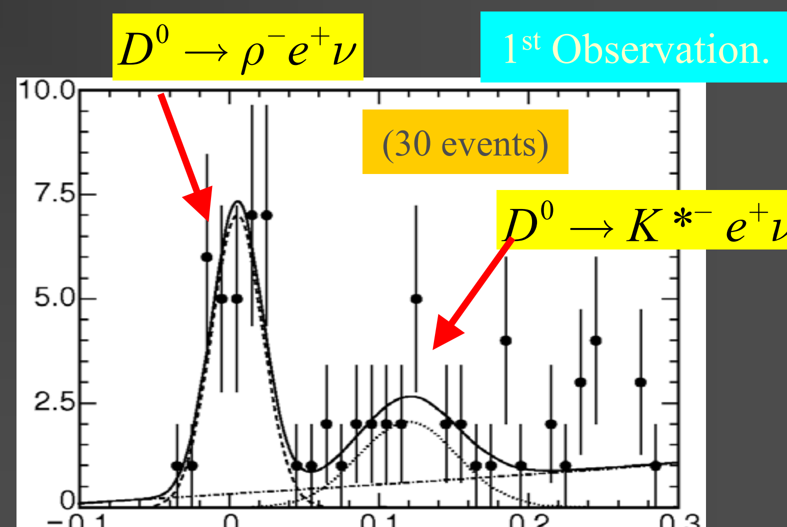
U = E_{miss} – $|P_{miss}|$ (GeV)



U = E_{miss} – $|P_{miss}|$ (GeV)



U = E_{miss} – $|P_{miss}|$ (GeV)

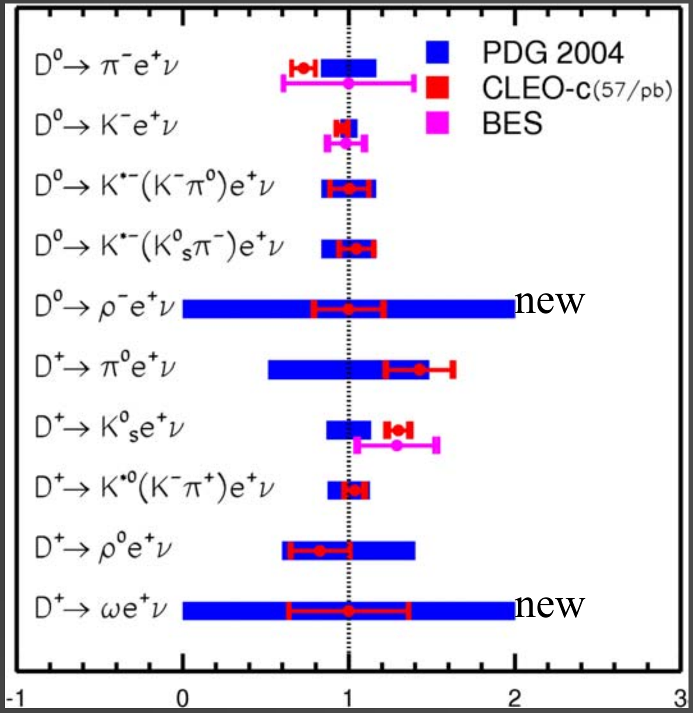


U = E_{miss} – $|P_{miss}|$ (GeV)

Summary of Semileptonic Branching Ratio Results

	Decay Mode	$\mathcal{B}$ (%) (CLEO-c/(57/pb))	$\mathcal{B}$ (%) (PDG-04)
1.	$D^0 \to \pi^- e^+ \nu$	$0.26 \pm 0.03 \pm 0.01$	0.36 ± 0.06
2.	$D^0 \to K^- e^+ \nu$	$3.44 \pm 0.10 \pm 0.10$	3.58 ± 0.18
3.	$D^0 \to K^{*-}(K^- \pi^0) e^+ \nu$	$2.16 \pm 0.24 \pm 0.11$	2.15 ± 0.35
4.	$D^0 \to K^{*-}(K^0_S \pi^-) e^+ \nu$	$2.25 \pm 0.21 \pm 0.11$	2.15 ± 0.35
5.	$D^0 \to \rho^- e^+ \nu$	$0.19 \pm 0.04 \pm 0.02$	—
6.	$D^+ \to \pi^0 e^+ \nu$	$0.44 \pm 0.06 \pm 0.03$	0.31 ± 0.15
7.	$D^+ \to \bar{K}^0 e^+ \nu$	$8.71 \pm 0.38 \pm 0.37$	6.7 ± 0.9
8.	$D^+ \to \bar{K}^{*0}(K^- \pi^+) e^+ \nu$	$5.70 \pm 0.28 \pm 0.25$	5.5 ± 0.7
9.	$D^+ \to \rho^0(\pi^+ \pi^-) e^+ \nu$	$0.21 \pm 0.04 \pm 0.02$	0.25 ± 0.10
10.	$D^+ \to \omega(\pi^+ \pi^- \pi^0) e^+ \nu$	$0.17 \pm 0.06 \pm 0.01$	—

Ratio to PDG



- Using unquenched lattice (hep-ph/0408306) find
- $V_{cs} = 0.956 \pm 0.036 \pm 0.093 \pm 0.017$
- $V_{cd} = 0.213 \pm 0.008 \pm 0.020 \pm 0.008$

stat lat   sys lat   exp CLEO

V_{cs} (LEP) $= 0.976 \pm 0.014$
$V_{cd}(\nu N) = 0.224 \pm 0.012$
Currently this checks Lattice calculations

Combining Semileptonics & Leptonics

- Semileptonic decay rate:

$$\frac{d\Gamma\left(D \to Pe\nu\right)}{dq^2} = \frac{\left|V_{cq}\right|^2 P_P^3}{24\pi^3}\left|f_+(q^2)\right|^2$$

- Note that the ratio below depends only on QCD:

$$\frac{1}{\Gamma\left(D^+ \to \ell\nu\right)}\frac{d\Gamma\left(D^+ \to \pi e\nu\right)}{dq^2} \,\alpha\, \frac{P_\pi^3\left|f_+(q^2)\right|^2}{f_{D^+}^2}$$

Lattice comparison: f_D and semileptonic ff

- We can use a quantity independent of V_{cd} to do a CKM independent lattice check:

$$R_{\ell sl} \equiv \sqrt{\frac{\Gamma(D^+ \to \mu \upsilon)}{\Gamma(D^+ \to \pi \ell \upsilon)}} \propto \frac{f_D}{f_+^{\pi}(0)}$$

- I obtain:

$$R_{\ell sl}^{th} = 0.22 \pm 0.02$$

$$R_{\ell sl}^{\exp} = 0.25 \pm 0.02$$

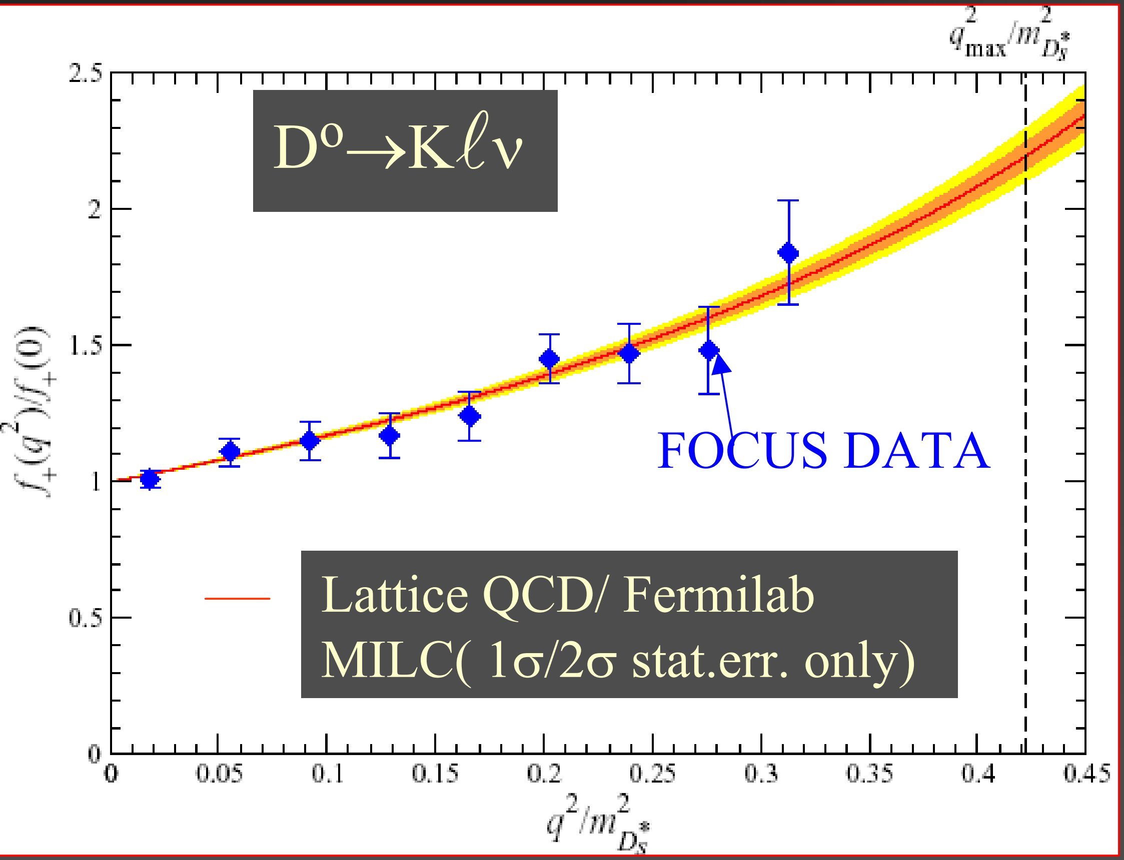
- Theory and data consistent at ~30% C.L.

Lattice comparison – the shape of $f_+(q^2)$

- Modern parameterization of the form factors proposed by Becirevic & Kaidalov (BK):

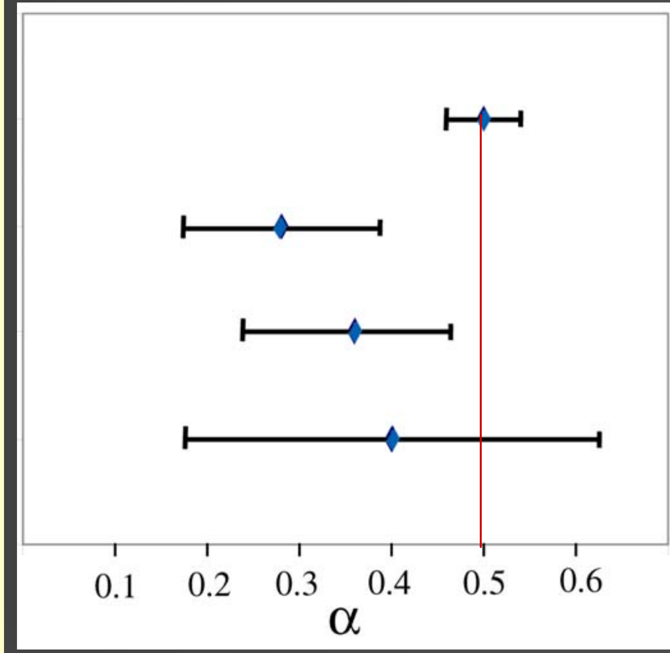
$$f_+(x) = f_+(0)\left(\frac{1}{(1-q^2/m^2_{D_s^*})}\underbrace{\frac{1}{(1-\alpha q^2/m^2_{D_s^*})}}_{}\right)$$

Representing contributions beyond the lowest lying resonances (D*)



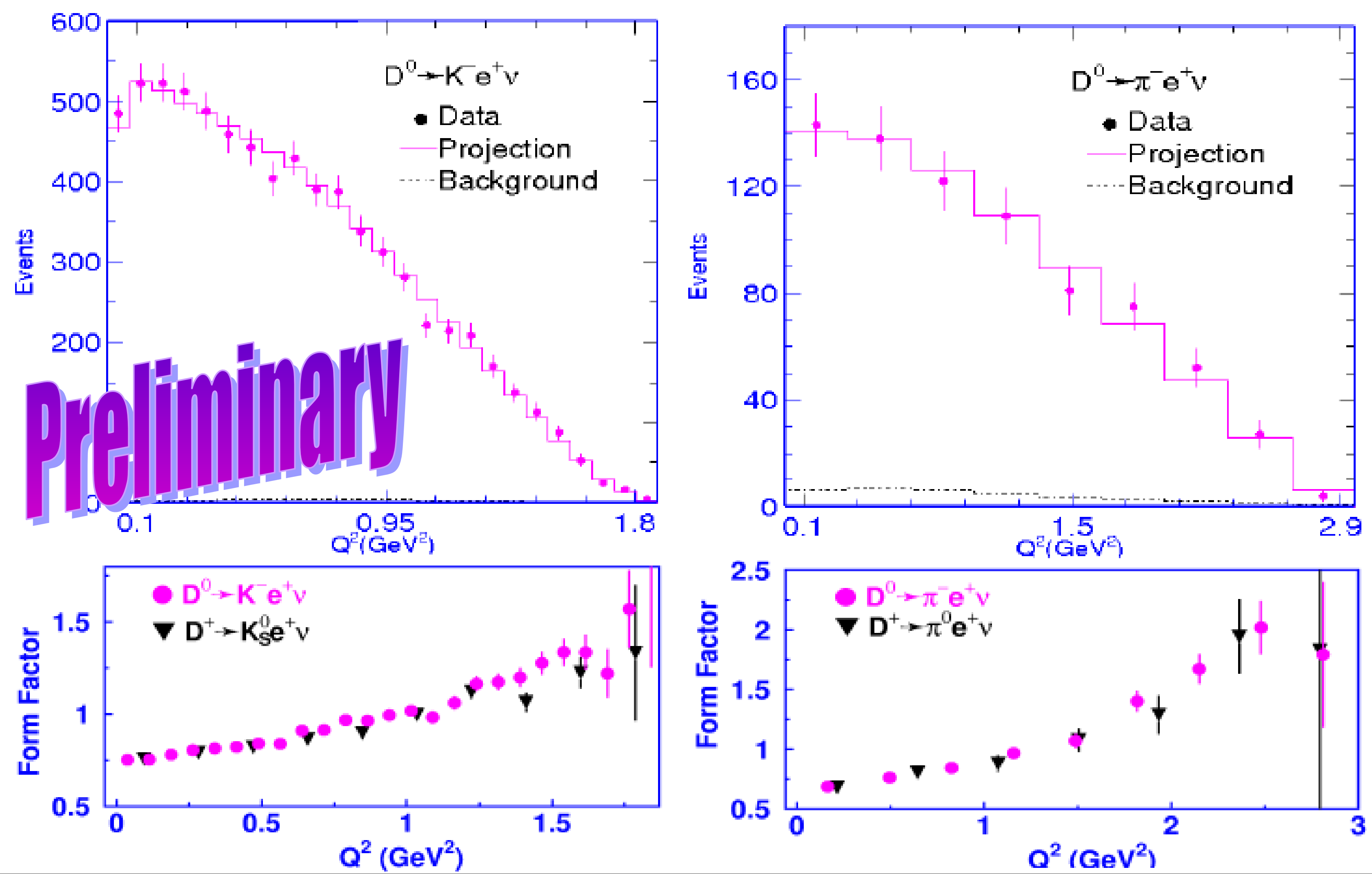
Form Factor shapes

$\alpha(D^o \to K\ell\nu)$	
Lattice (Fermilab-MILC hep-ph/0408306)	0.50±0.04(stat)
FOCUS	0.28 ±0.08 ±0.07
CLEO III	0.36 ±0.10 $^{+0.03}_{-0.07}$
Belle	0.40 ±0.12 ±0.19
$\alpha(D^o \to \pi\ell\nu)$	
Lattice (Fermilab-MILC hep-ph/0408306)	0.44 ±0.04(stat)
CLEO III	0.37 $^{+0.20}_{-0.31}$ ±0.15
Belle	0.03 ±0.27±0.13



CLEOc results soon

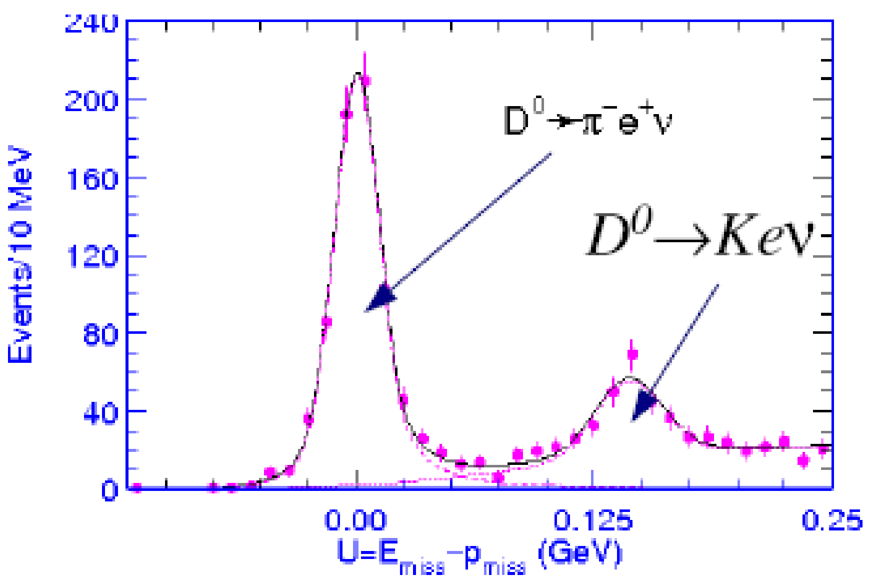
Q^2 Distributions for 281 pb^{-1}



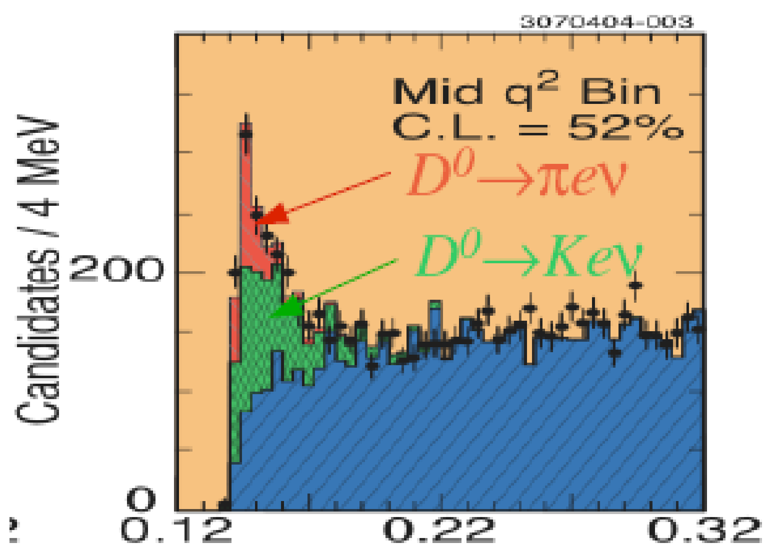
Comparison of Techniques

- Superior method allows for clean signals with small amounts of data

CLEO-c 281 pb^{-1} (Preliminary)

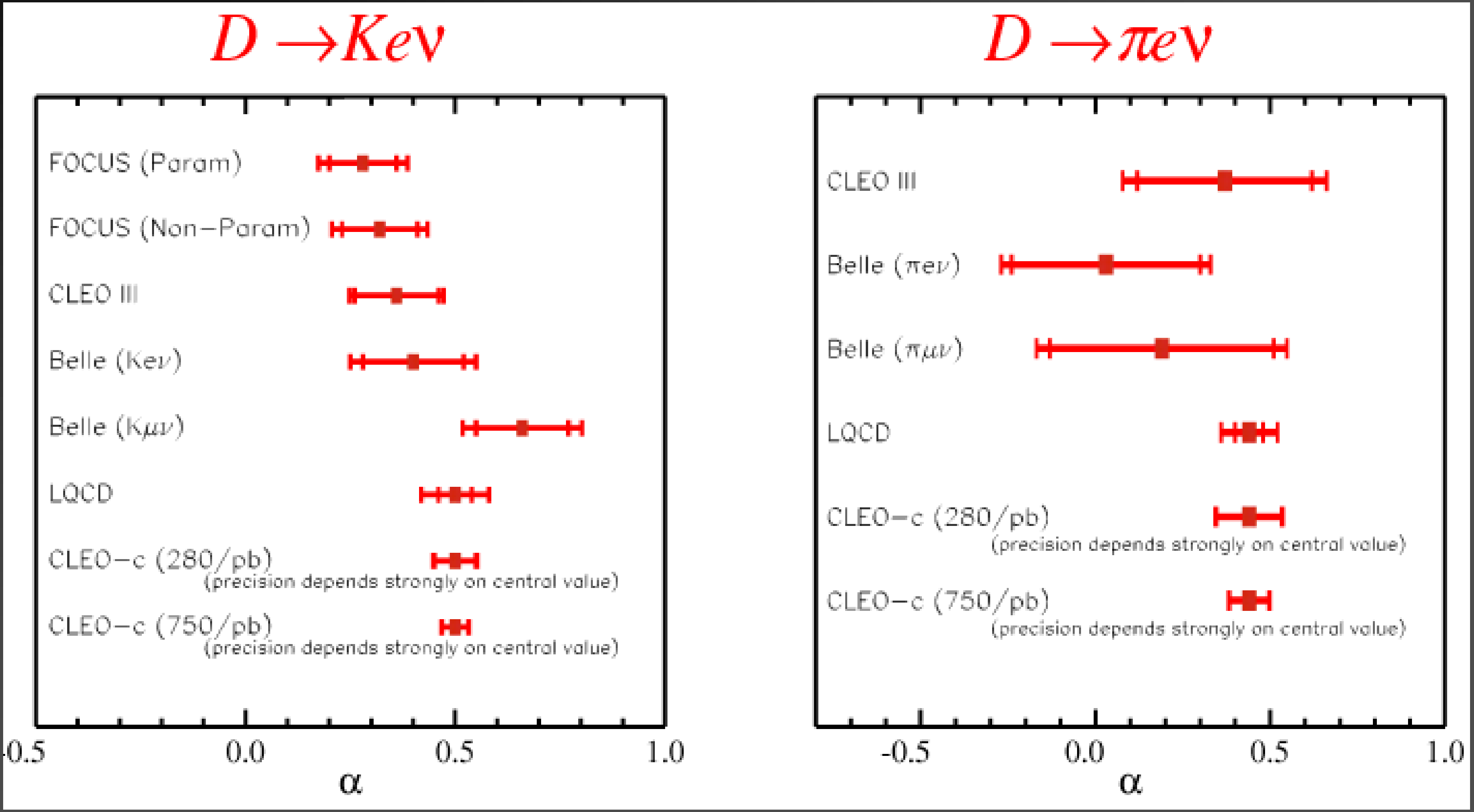


CLEO-III 7 fb^{-1} (PRL 94:011802, 2005)



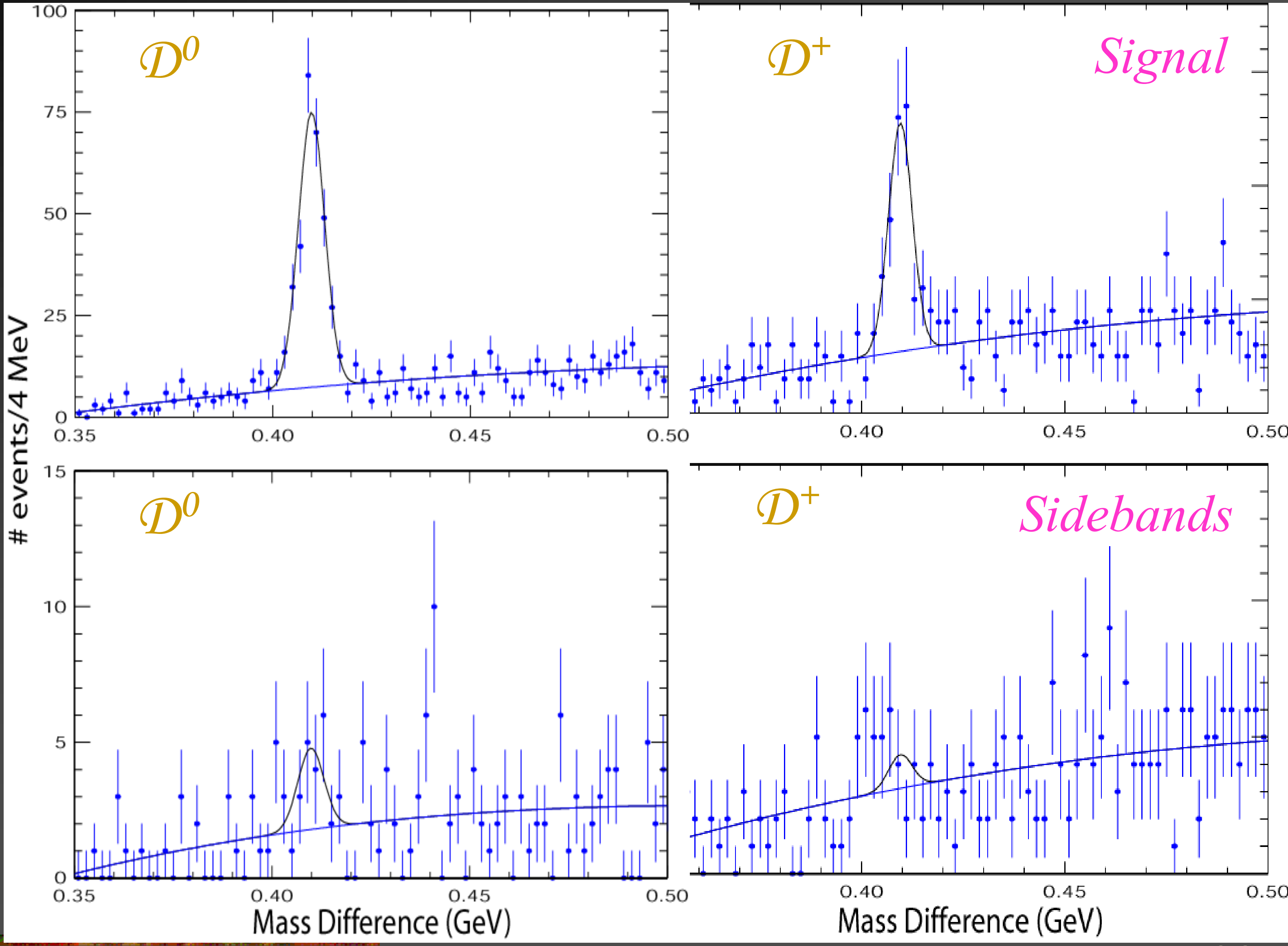
$M(\pi^+ D^o)$-$M(D^o)$

Expected Precision on α

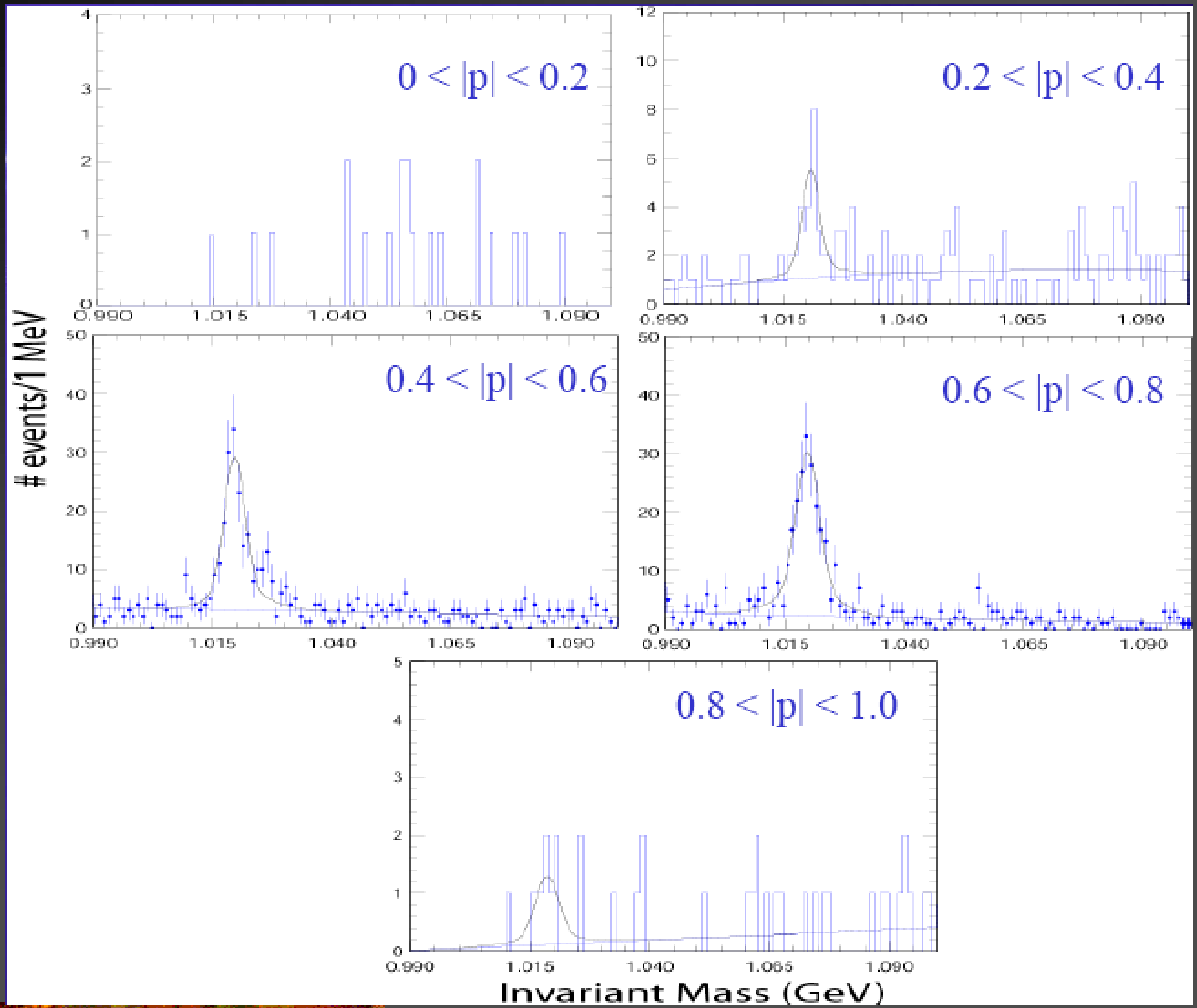


Inclusive Charm → η, η′, φ

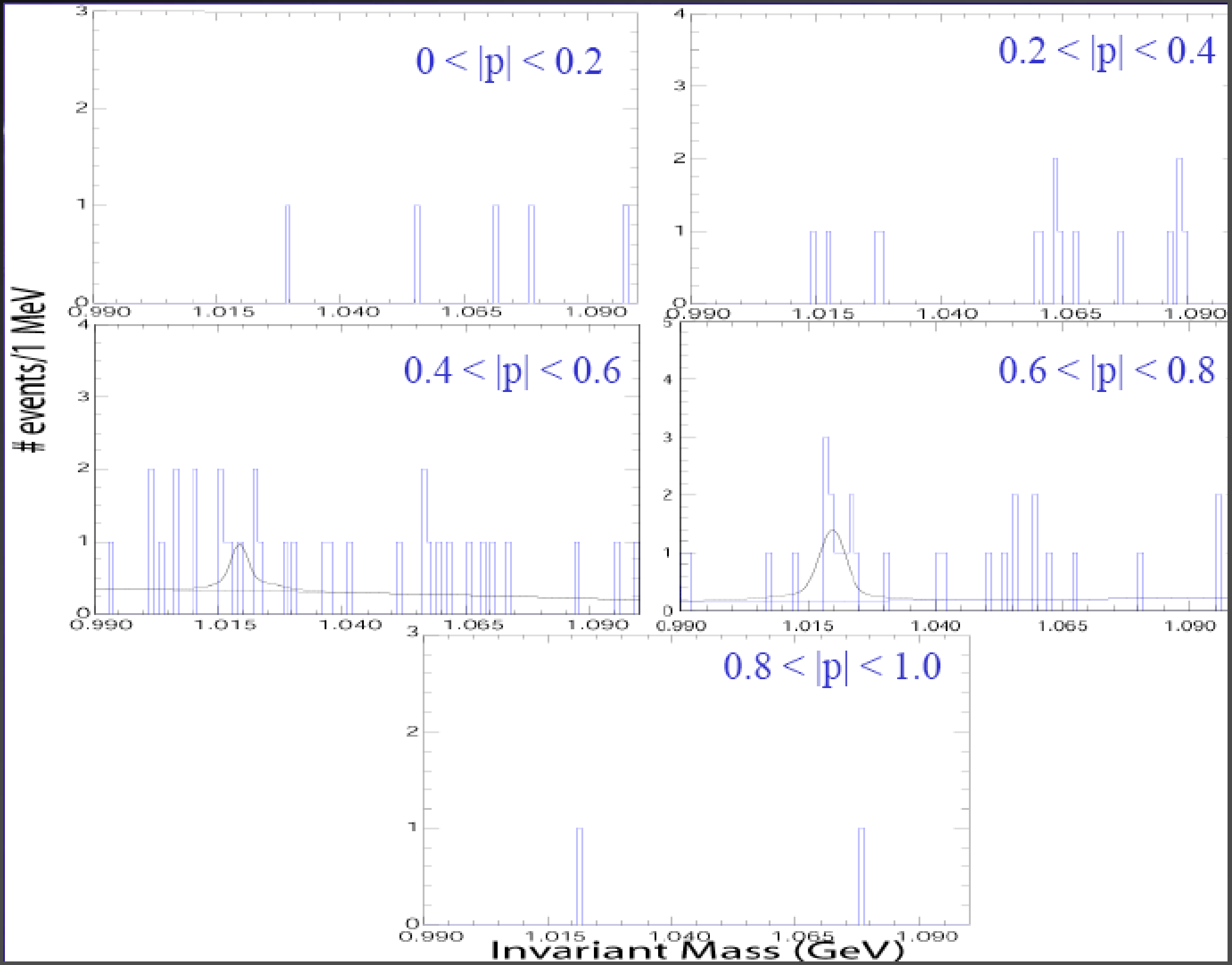
η′ →
ηπ⁺π⁻,
η →γγ



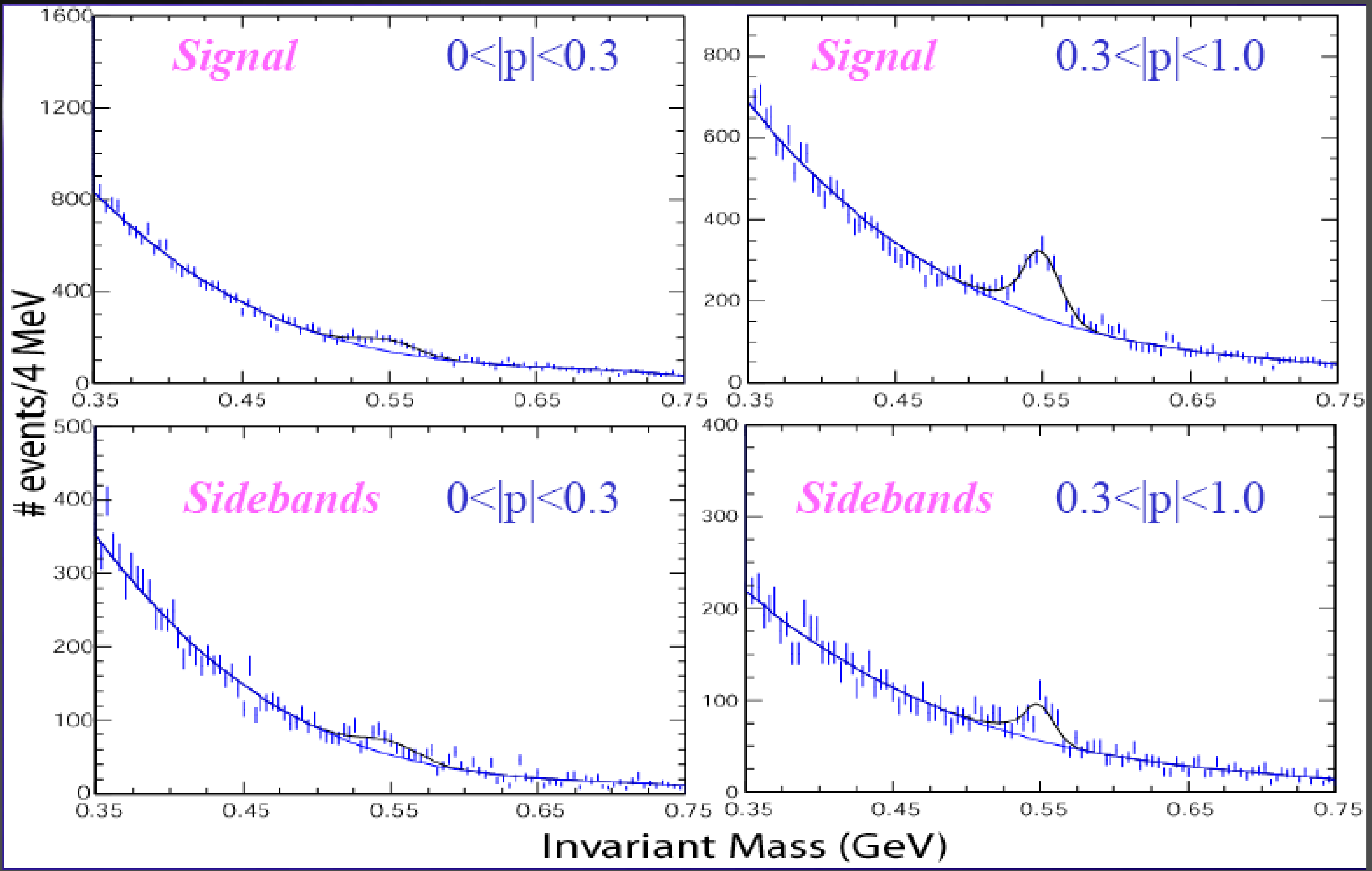
$D^o \to \phi$ X Signal



D^o→ϕ X Sidebands



D°→η X



Signal
0<|p|<0.3
Signal
0.3<|p|<1.0
Sidebands
0<|p|<0.3
Sidebands
0.3<|p|<1.0
events/4 MeV
1600
1200
800
400
0
800
600
400
200
0
500
400
300
200
100
0
400
300
200
100
0
0.35
0.45
0.55
0.65
0.75
Invariant Mass (GeV)

Inclusive Charm Results

Mode	Our Measurement (%)	PDG (%)
$\mathcal{B}(D^0 \to \eta X)$	$= 9.4 \pm 0.4 \pm 0.5$	$< 13\%$
$\mathcal{B}(D^0 \to \eta' X)$	$= 2.6 \pm 0.2 \pm 0.2$	--
$\mathcal{B}(D^0 \to \phi X)$	$= 0.99 \pm 0.08 \pm 0.05$	1.7 ± 0.8
$\mathcal{B}(D^+ \to \eta X)$	$= 5.7 \pm 0.5 \pm 0.3$	< 13
$\mathcal{B}(D^+ \to \eta' X)$	$= 1.0 \pm 0.2 \pm 0.1$	--
$\mathcal{B}(D^+ \to \phi X)$	$= 1.11 \pm 0.14 \pm 0.14$	< 1.8

- A useful tool for finding B_S decays, expect large rates to ϕ & η' from D_S decays ~15%
- Note $B(B\to\phi X)$=3.5%, contribution from $B(B\to D^o + D^+ X + \Lambda_C)$ ~ 100%, is ~1% & $B(B\to D_S X)$ = 15% (?), giving 1.0% + 2.3% = 3.3%

Next From CLEOc: The D_S^+

- Some reasons why we want to study the D_S
- Very Preliminary Results from an Energy Scan

Theoretical Predictions for f_{D_S}

- Models predict f_{D_S}/f_{D^+}~1.1-1.3, with unquenched lattice giving large ratio of 1.24, or 250 MeV

Model	f_{D^+} (MeV)	$f_{D_s^+}/f_{D^+}$
Lattice (n_f=2+1) [13]	$201 \pm 3 \pm 17$	$1.24 \pm 0.01 \pm 0.07$
QL (Taiwan) [14]	$235 \pm 8 \pm 14$	$1.13 \pm 0.03 \pm 0.05$
QL (UKQCD) [15]	$210 \pm 10^{+17}_{-16}$	$1.13 \pm 0.02^{+0.04}_{-0.02}$
QL [16]	$211 \pm 14^{+0}_{-12}$	1.10 ± 0.02
QCD Sum Rules [17]	203 ± 20	1.15 ± 0.04
QCD Sum Rules [18]	195 ± 20	
Quark Model [19]	243 ± 25	1.10
Potential Model [20]	238	1.01
Isospin Splittings [21]	262 ± 29	

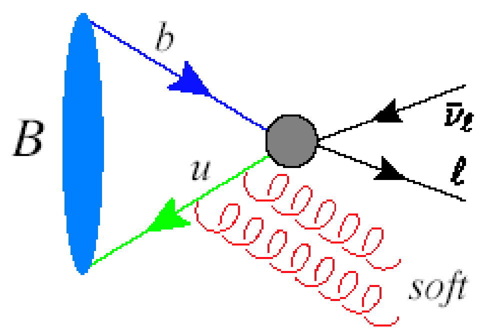
- Important to check for breakdown of lepton universality due to New Physics where:

$$\frac{\Gamma(D_{(s)}^+ \to \tau^+ \nu)}{\Gamma(D_{(s)}^+ \to \mu^+ \nu)} \neq \frac{m_\tau^2 \left(1-m_\tau^2/M_{D_S}^2\right)^2}{m_\mu^2 \left(1-m_\mu^2/M_{D_S}^2\right)^2}$$

Study of Inclusive Semileptonic Decays

- Is the semileptonic width, $\Gamma_{s\ell} = B_{s\ell} \bullet \Gamma_{tot} = B_{s\ell}/\tau_D$, the same for D^o, D^+ & D_s?
- Problem of Weak Annihilation in V_{ub} meas.

(Bigi & Uraltsev, Voloshin, Ligeti, Wise and Leibovich)



Gluons break helicity suppression

$$O\left(16\pi^2 \times \frac{\Lambda^3_{QCD}}{m_b^3} \times \text{factorization violation}\right) \sim 0.03 \left(\frac{f_B}{0.2\,\mathrm{GeV}}\right)\left(\frac{B_2 - B_1}{0.1}\right)$$

~3% (?? guess!) contribution to rate at $q^2 = m_b^2$

- an issue for all inclusive determinations
- relative size of effect gets worse the more severe the cut
- no reliable estimate of size

Inclusive Semileptonic Decays II

- Voloshin predicts that this effect, if it exists, will cause a difference between the semileptonic widths of the D^o & D_s mesons

$$\Gamma_{sl}(D^o)-\Gamma_{sl}(D_s^+)\approx 1.1\left(\frac{f_D}{0.22\text{GeV}}\right)^2\left(B_1-B_2\right)\text{ps}^{-1}\approx .1\text{ps}^{-1}$$

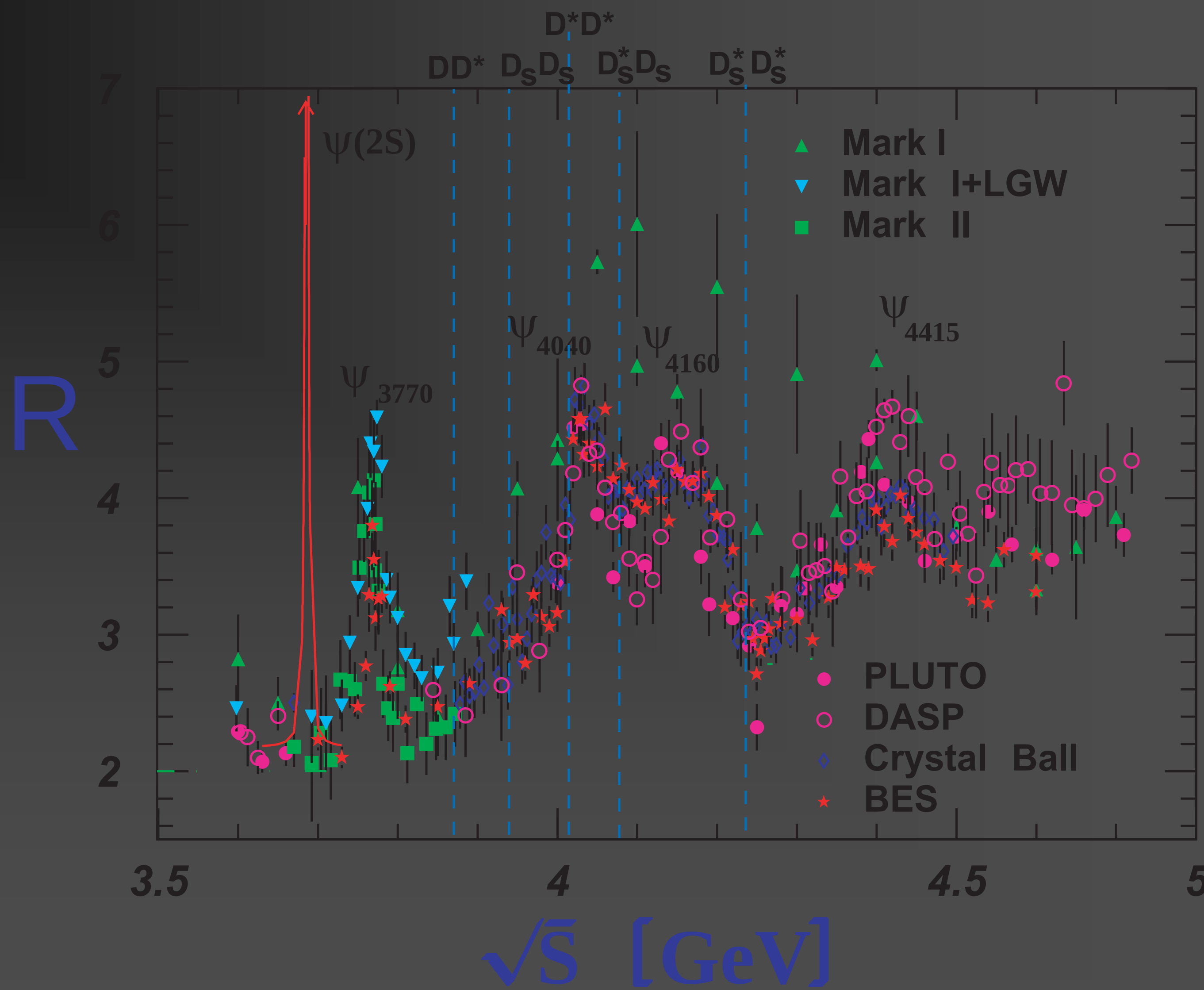
- We have already measured $\Gamma_{s\ell}(D^o)=0.157\pm0.006\ \text{ps}^{-1}$, so we will measure or limit B_1-B_2
- One of the best places to look as the annihilation in D_S is Cabibbo favored
- *(Voloshin hep-ph/0106040)*

The Absolute Branching Ratio

- Current Status
  - CLEO & BaBar measurements of $\mathcal{B}(D_S^+ \to \phi\pi^+)$ with poor accuracy of (3.6±0.9)% & (4.8±0.6)%, respectively
- This number is an important engineering number for understanding many B decays especially for B_s, very important at hadron colliders

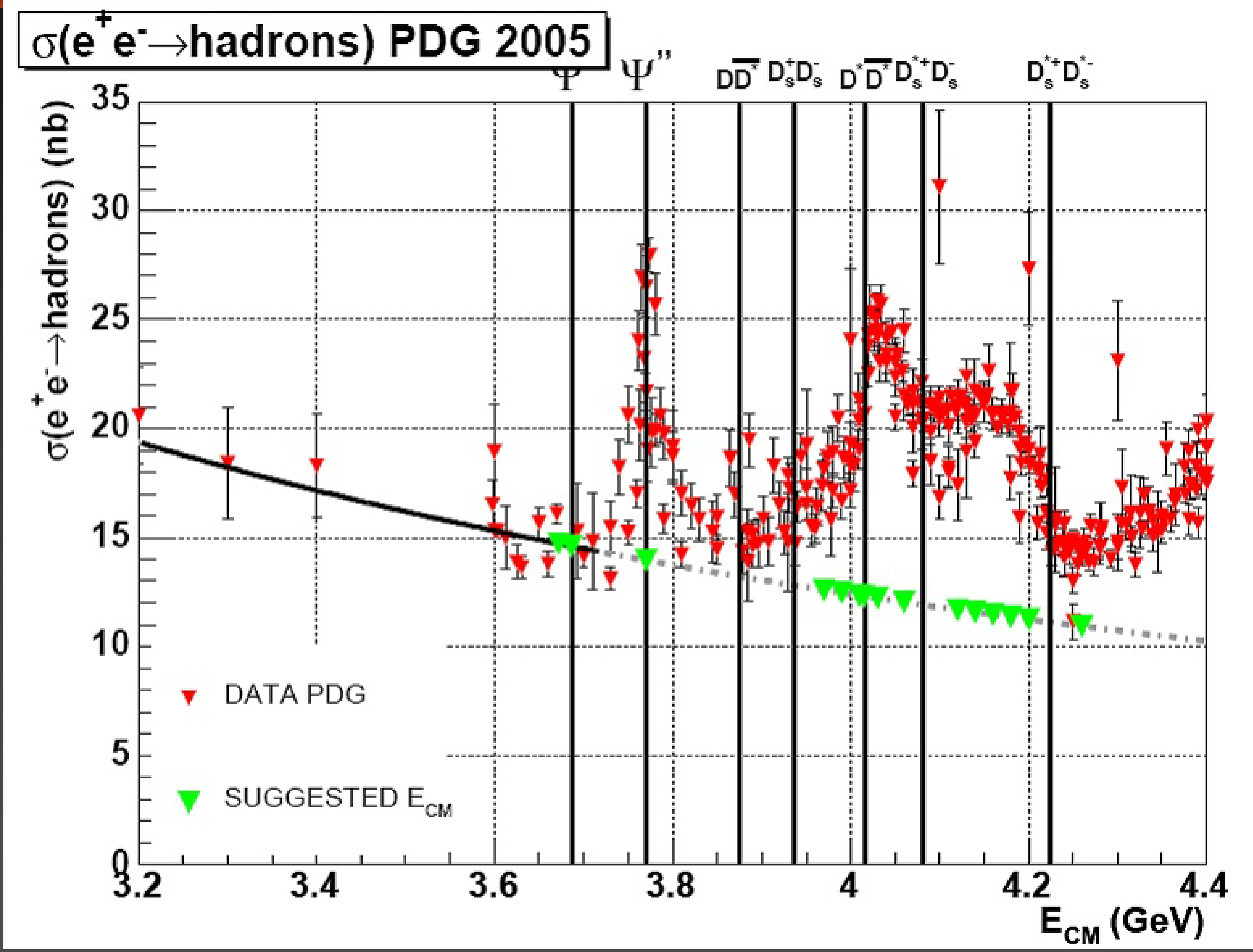
The Charm Region

$$R=\frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$



The Charm Region

What is best energy to Study D_S?



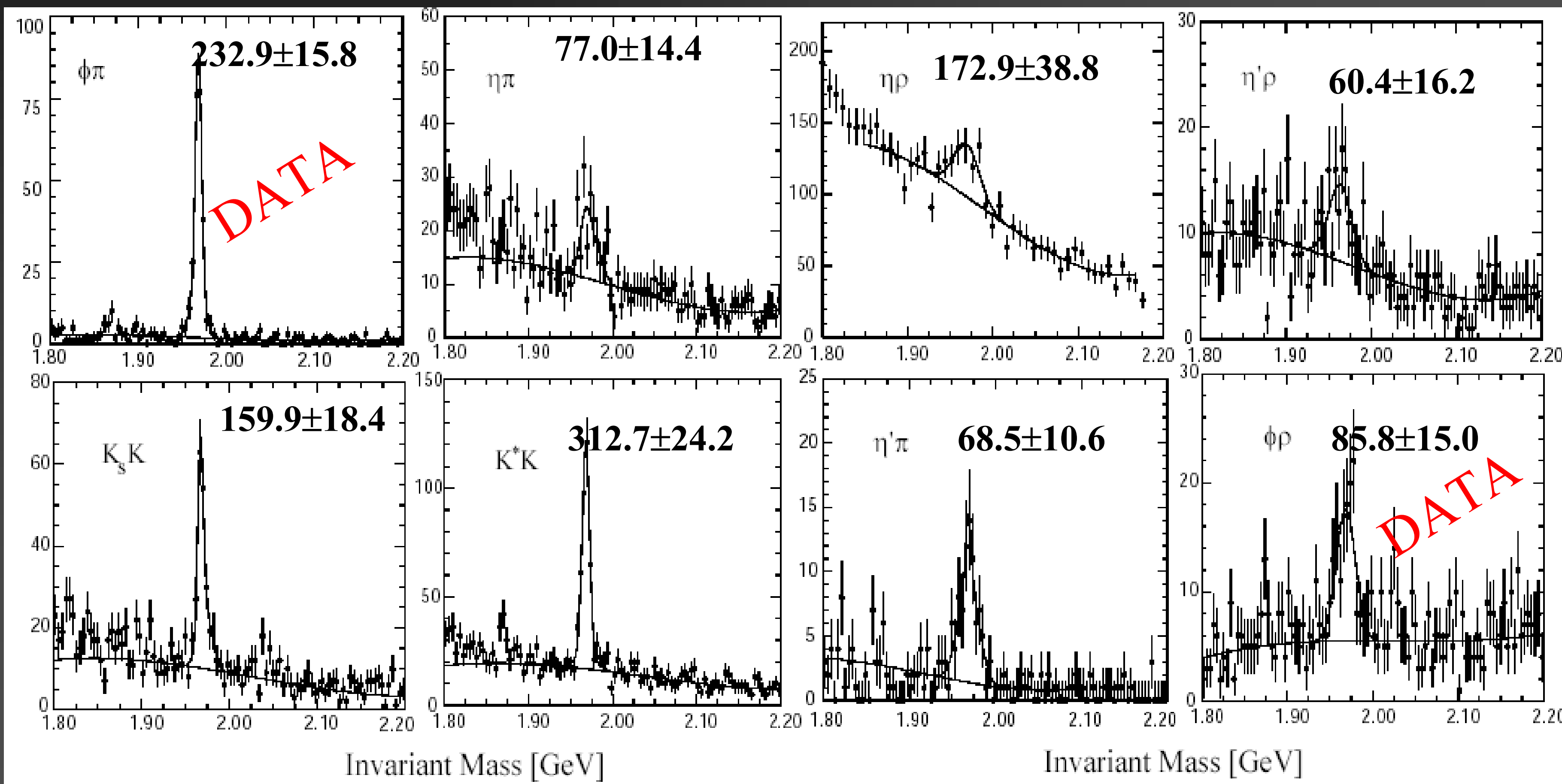
Decay Modes & Search Strategy

- D^0 decays mode
  - $K^-\pi^+$
  - $K^-\pi^+\pi^0$
  - $K^-\pi^+\pi^+\pi^-$
- D^+ decays mode
  - $K^-\pi^+\pi^+$
  - $K^-\pi^+\pi^+\pi^0$
  - $K_s\pi^+$
  - $K_s\pi^+\pi^0$
  - $K_s\pi^+\pi^-\pi^+$
  - $K^+K^-\pi^+$
- D_s decays modes
  - $\phi\pi^+, \phi \to K^+K^-$
  - $K^{*0}K^+, K^{*0} \to K^-\pi^+$
  - $\eta\pi^+, \eta \to \gamma\gamma$
  - $\eta\rho^+, \eta \to \gamma\gamma, \rho^+ \to \pi^+\pi^0$
  - $\eta'\pi^+, \eta' \to \pi^+\pi^-\eta$
  - $\eta'\rho^+, \eta' \to \pi^+\pi^-\eta, \rho^+ \to \pi^+\pi^0$
  - $\phi\rho^+, \phi \to K^+K^-, \rho^+ \to \pi^+\pi^0$
  - $K_sK^+, K_s \to \pi^+\pi^-$

- Take ~5 pb^{-1} per E_{cm} point, analyze online for fast feedback; can stop early if no D_S signals. **$p(D_S)$** shows if D_SD_S, $D_S{}^*D_S$, etc

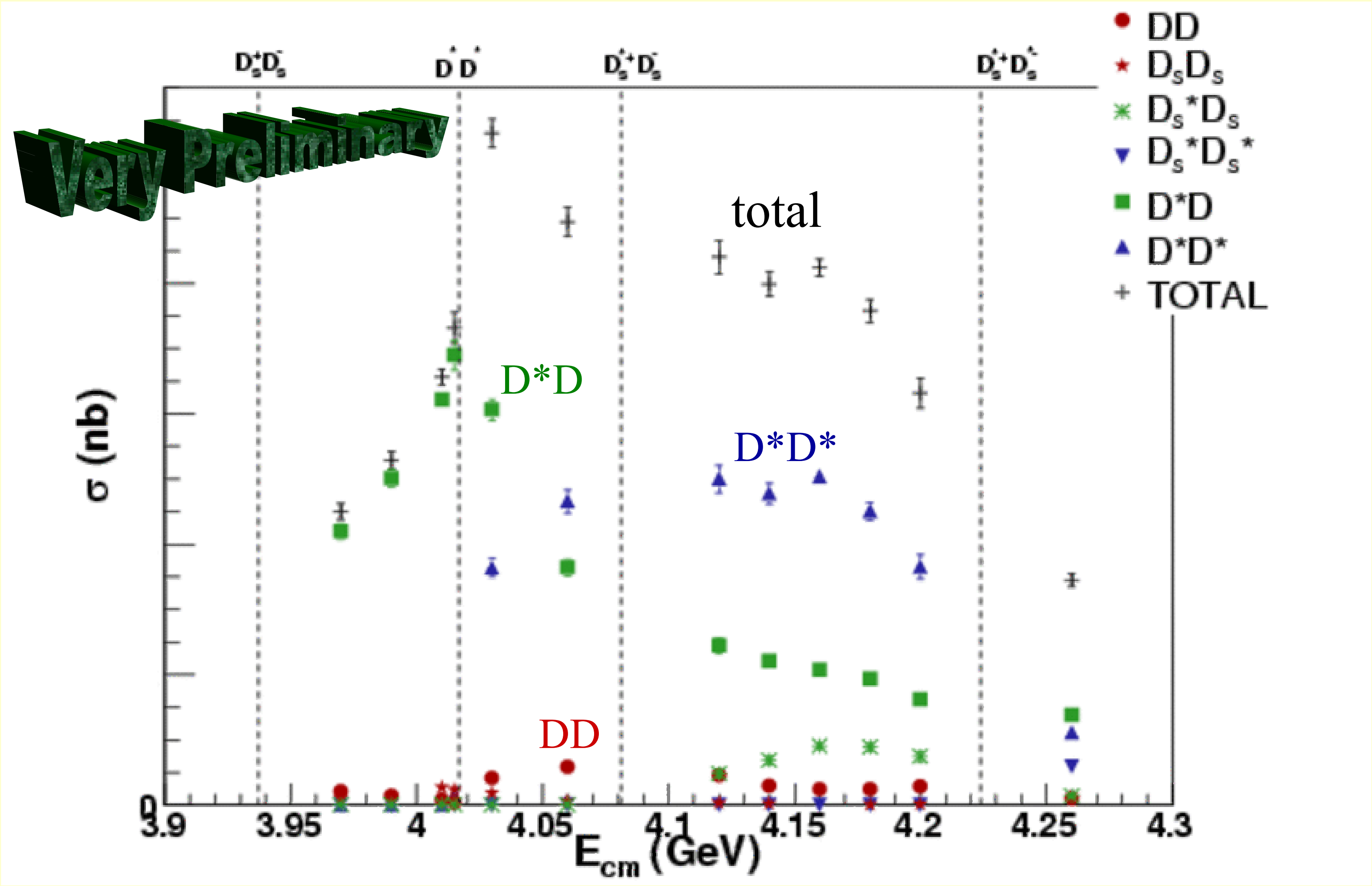
Some D_S Modes at 4160 + 4180 MeV

- Total of 15.8 pb^{-1}, D_S energy $\Rightarrow$ no $D_S^+ D_S^-$
- $\sigma(D_S^* D_S)$ nearly equal at both energies



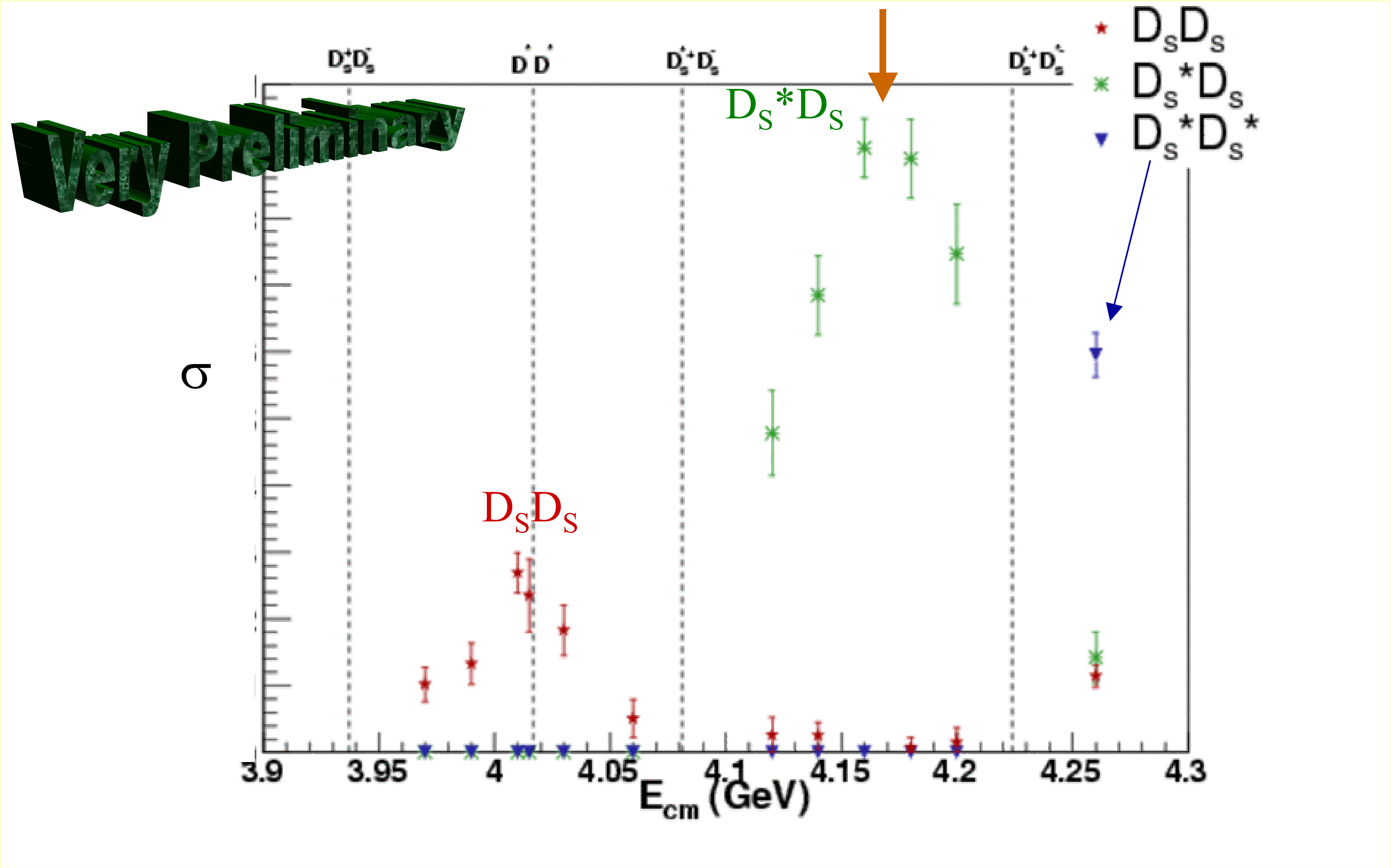
TOTAL of = 1170 ±46 D_S events

CLEO-c Energy Scan Results



Relative D_s Yields

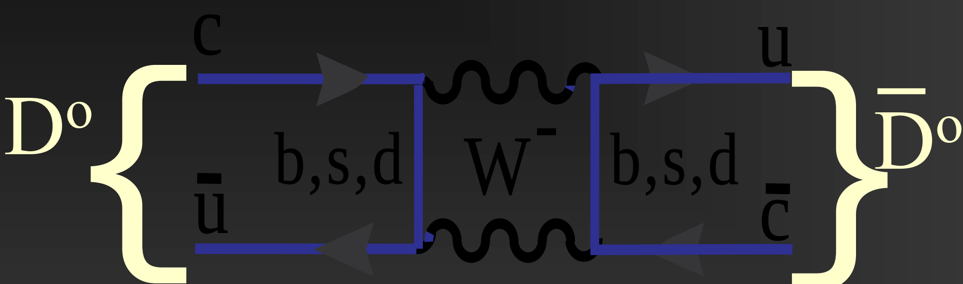
Maximum at 4170 MeV



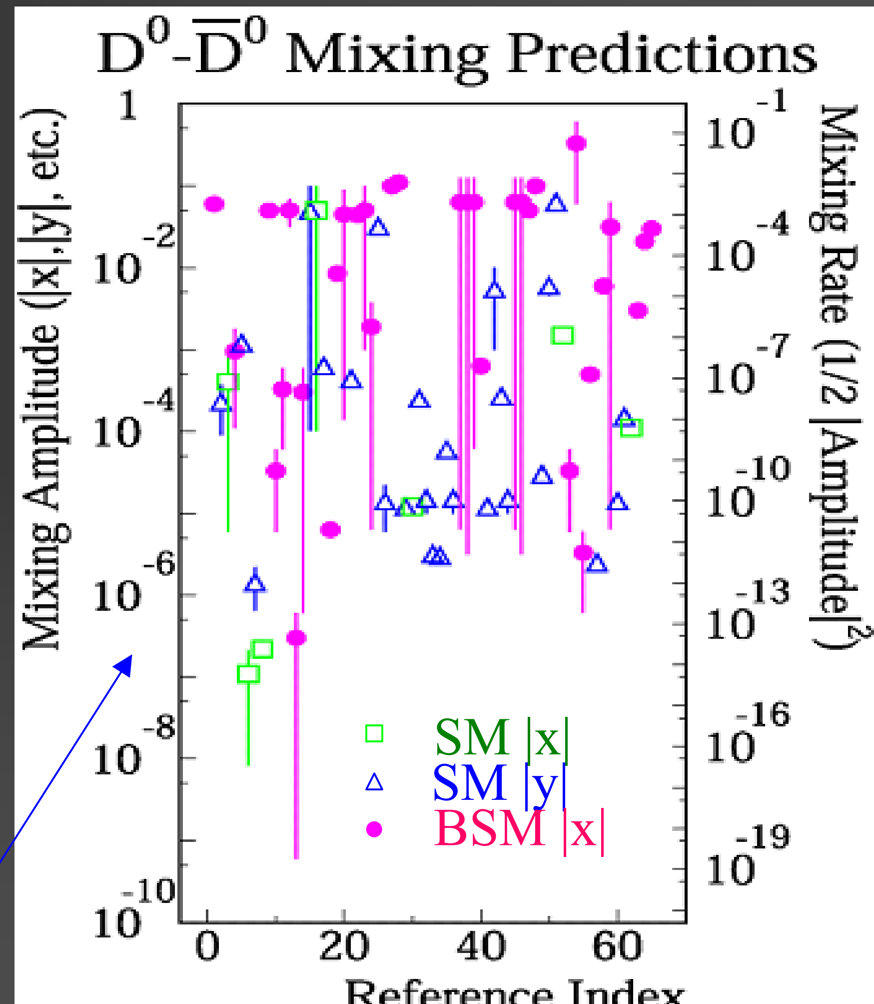
Searches for New Physics in Charm Decays

D^o-$\bar{D}^o$ Mixing

- Mixing could proceed via



- the presence of d-type quarks in the loop makes the SM expectations for D^o- $\bar{D}^o$ mixing small compared with systems involving u-type quarks in the box diagram because these loops include 1 dominant super-heavy quark (t): K^o (50%), B^o (20%) & B_s (50%)
- New physics in loops implies x $\equiv \Delta M/\Gamma >>$ y $\equiv \Delta\Gamma/2\Gamma$; but long range effects complicate predictions



From H. Nelson

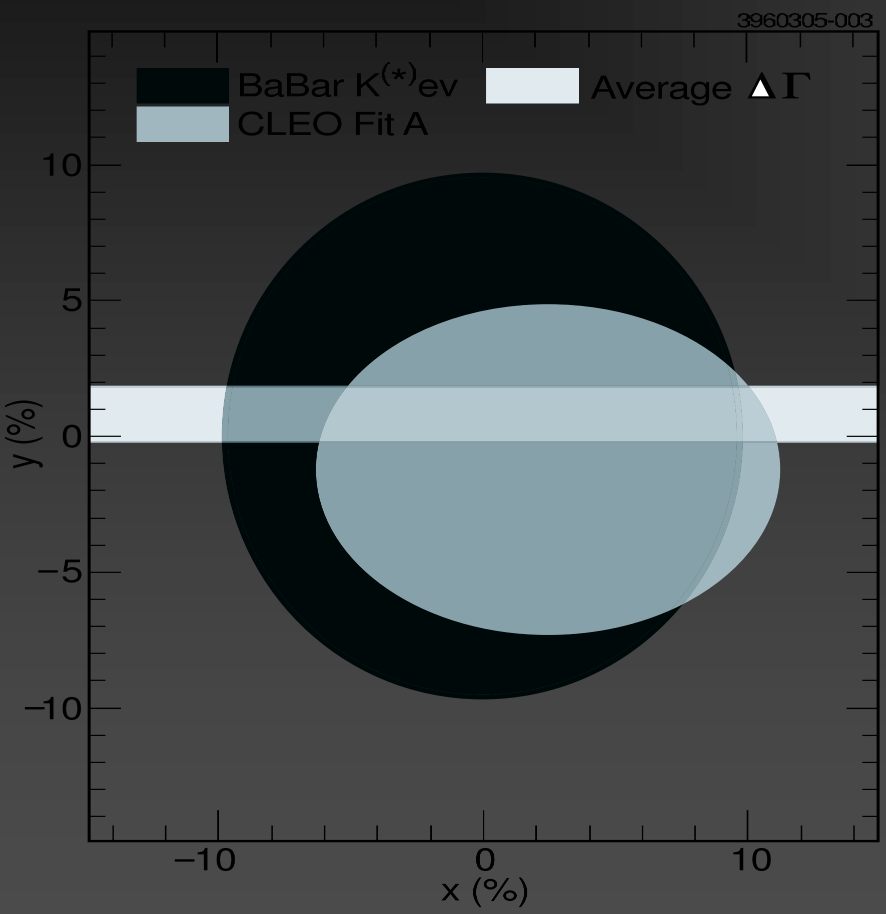
D^o- $\bar{D}^o$ mixing: the data

- The study of D^o wrong-sign $K\pi$ yields has been a key step in our experimental study of $D^o \bar{D}^o$ mixing.
- Caveats:
  - Complicated by interference between DCSD & mixing [strong phase $\delta \Rightarrow$ data constrain only x' & y']
  - Complicated by CP violation

Experiment	x'^2 (95 % C.L.) ($X10^{-3}$)	y'(95% C.L.) ($X10^{-3}$)
Belle (2004)	0.81	$-8.2<y'<16$
BaBar (2003)	2.2	$-56<y'<39$
FOCUS (2001)	1.52	$-124<y'<-5$
CLEO II.V (2000)	0.82	$-58<y'<10$

Most general fit

$D^o \bar{D}^o$ mixing: the data II



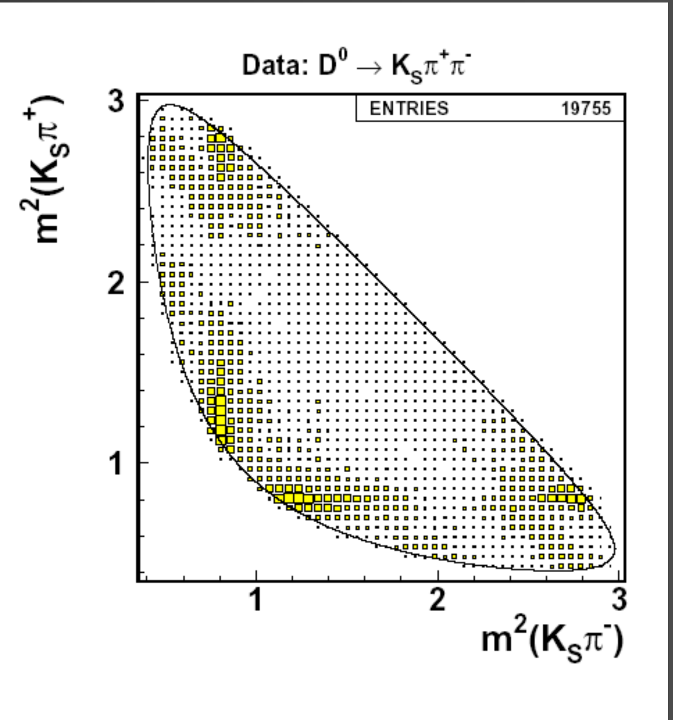
- D^o semileptonic decays: $R_{ws} = ½(x^2+y^2)$ [no strong phase δ]

Experiment	R_M(95% CL)	$\sqrt{x^2+y^2}$
BaBar 04	0.0046	0.1
Belle 05	0.0016	0.056

- Dalitz plot analysis of $D^0 \rightarrow K^0_s \pi^+\pi^-$ (CLEO II.V) comparable sensitivity

$D^o \to K_s\pi^+\pi^-$ Dalitz Analysis for γ

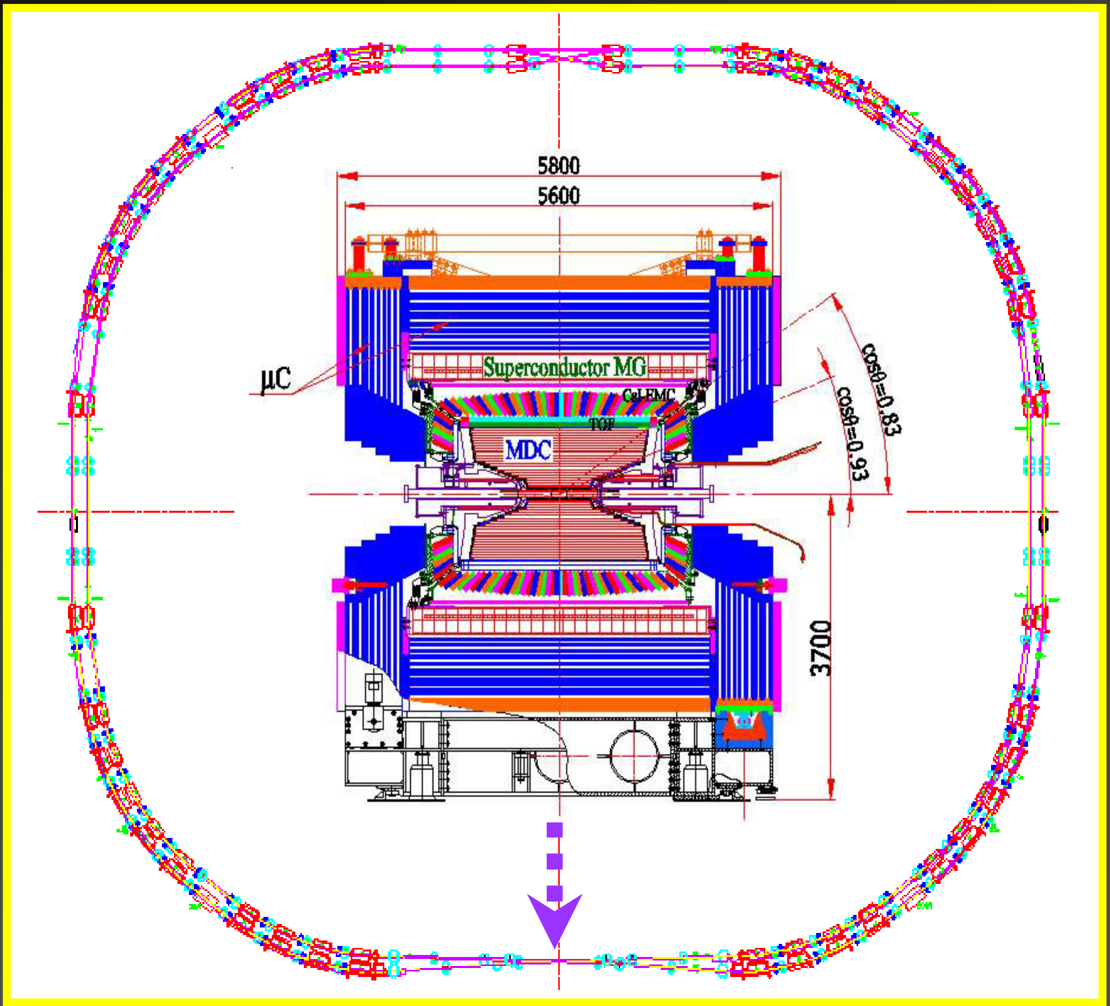
- CLEOc data can be used to find phase shifts that can be used for input in the γ angle determination from $B^\pm \to D^o K^\pm$ decays, when $D^o \to K_s\pi^+\pi^-$
- Measure Dalitz plot opposite a CP eigenstate tag such as K^+K^- or $K_s\phi$.



Future

- Immediate: Take data on D_s
- CLEO runs until April 2008. Most of the running is now planned to be on ψ'' & $\psi(4170)$ for D_s, with some on ψ'
  - Errors will depend on how much data CLEO-c gets on charm
- Beijing has started building a two-ring machine for this physics with much more projected luminosity

BEPCII/BESIII Project



Design

- Two ring machine
- 93 bunches each
- Luminosity

  10^{33} cm^{-2} s^{-1} @1.89GeV

  6×10^{32} cm^{-2} s^{-1} @1.55GeV

  6×10^{32} cm^{-2} s^{-1} @ 2.1GeV
- New BES III detector

Status & Schedule

- Most contracts signed
- Linac installed - 2004
- Ring installed - 2005
- BESIII in place - 2006
- Commissioning

  BEPCII/BESIII

  beginning of 2007

The End